

MMPC-009
MANAGEMENT OF
MACHINES AND
MATERIALS

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BLOCK-1

**OPERATIONS MANAGEMENT — AN
OVERVIEW AND FACILITIES PLANNING**

- UNIT 1 Operations Management — An Overview**
- UNIT 2 Product Selection and Process Selection**
- UNIT 3 Facilities Location**
- UNIT 4 Facilities Layout and Material Handling**

BLOCK-1 OPERATIONS MANAGEMENT –AN OVERVIEW AND FACILITIES PLANNING

The first unit of this block introduces the subject of operations management which is equally applicable to products and services. The unit explains the objectives of the operations management and tries to develop an understanding of scientific approach to industrial engineering. It gives a bird's eye view of managerial functions involved in operations management.

Block 1 has four units dealing with different aspects impinging on the planning of various facilities. Facilities here refer to production plants and other facilities for service institutions like hospitals, colleges, banks and airports etc. The first stage of facilities planning is selection of product. The issues concerned with product selection are thus discussed in Unit 2. After product (or type of service) selection has been made, one has to select the process (discussed in same Unit 2). Where the facility should be located becomes the next question. There is a lot of considerations related to this question which are discussed in details in Unit 3. Once the facilities has been decided, the layout of facilities has to be done--discussed in Unit 4. A mention is also made of different materials handling equipment. Finally in Unit 5, Capacity planning is discussed. The related issues of demand forecasting and capacity planning are also discussed. A number of quantitative or operations research techniques have been referred to, in this block. These techniques are not fully discussed here since their details would be handled in other courses to follow.

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UNIT 1 OPERATIONS MANAGEMENT - AN OVERVIEW

Objectives

Upon completion of this unit, you should be able to:

- know the production/operation function as process of value addition, understand the system concepts in operations management and problems in decision making in OM and recognize the difference between product and services.
- Appreciate the role of materials management and know the concept of systems life cycle.
- Have a brief idea of the historical profile of development of operations management.

Structure

- 1.1 Introduction
- 1.2 Systems Concepts in Operations Management
- 1.3 Objectives in Operations Management
- 1.4 Operations Management Decisions
- 1.5 Types of Production Systems
- 1.6 Management of Materials in Production Systems
- 1.7 Concepts in System Life-cycle
- 1.8 Role of Scientific Method in Operations Management
- 1.9 Historical Development of Operations Management
- 1.10 Summary
- 1.11 Key words
- 1.12 Self-assessment Exercises
- 1.13 Further Readings

1.1 INTRODUCTION

In this unit you will learn about the aspects of management of production and service organizations. For long the term ‘production’ has been associated only with a factory like situation where goods are produced in the physical sense. Factory has been defined as “.....any premises in which persons are employed for the purpose of making altering, repairing ornamenting, finishing, cleaning, washing, breaking, demolishing or adopting for sale, any article”.

However, by generalising the concept of production as “process through which goods and services are created” we can include both manufacturing

and service organizations within the purview of production management. Thus the essential features of the production are to bring together people, machines and materials to provide goods or services thereby satisfying the wants of the people.

Inclusion of services within the scope of production enables us to look at the problem of production management in a much wider perspective. This brings a number of seemingly non-manufacturing sectors of economy such as transport, energy, health, agriculture, warehousing, banking etc. within the scope of production systems. That is why the terms production and operations management or operations management have been suggested by many to indicate the general applications of the techniques of management of machines and materials.

Operations Management may be defined as the design, operation and improvement of the production systems that creates the firm's primary products or services.

The broad concept of production is kept in mind throughout this book although the apparent emphasis may be on techniques used in the context of manufacturing organisation but you should always be able to extend and apply these management techniques to all types of service organisations as well.

The Value Added Process

Perhaps a more general concept of 'operations' instead of 'production' will better include both manufacturing as well as service organisations. Operations-either in manufacturing or in service-are purposeful activities of an organisations. Operations function is the heart of and indeed the very reason for an organisation to come into being. All operations can be said to add value to some object thereby enhancing its usefulness. **We may formally define an operation as "the process of changing inputs into outputs and thereby adding value to some entity; this constitutes the primary function of virtually every organisation"**

Now let us consider how value can be added to an entity by performing an 'operation' function. There are four major ways:

- a) **Alter:** This refers to change in the form or state of the inputs. This change may be physical as in manufacturing, or sensual or psychological such as the feeling of comfort or satisfaction after getting cured from an illness.
- b) **Transport:** The entity gets value added through transport because it may have more value if located somewhere other than where it currently is. Entity may include, people, goods or garbage.

- c) **Store:** The value is enhanced if the entity is kept in a protected environment for some period of time, such as potatoes in cold storage or food grains in warehouses.
- d) **Inspect:** The value of an entity may be enriched through an inspection as we better understand its properties and can therefore take more informed decisions regarding their purchase, use, repair etc.

Thus we see that the value may be added to an entity through a number of different means. It may directly change in space, in time or even just in our mental image of it. All these processes can be called 'operations'. Thus almost every organization-manufacturing, transportation, warehousing, health-care, education etc. come within the purview of operations management.

Products and Services

The output of an operations (or production) system may be in terms of end-product-physical goods such as automobiles or rendering a service such as in transportation, hospitals, educational institutions, cinema-halls, beauty parlours and banks etc. Rendering a service may involve physical goods (or facilitating goods) such as a dentist making a set of false teeth while rendering dental care. Thus services can be considered as bundles of benefits, some may be tangible and others intangible (such as reduced waiting, courteous calls, convenient location etc.) and these may or may not be accompanied by facilitating goods. Based on this grouping it is possible to segregate organisations producing goods or services or both.

The Conversion Process

From the foregoing description, it should now be clear that all production of operation functions are essentially a part of the conversion process which transforms entities in shape, size, form, location, space, time and state. Hence every organisation can be considered essentially as a conversion system which converts inputs into outputs through the conversion process (or operations). This aspect is further highlighted in the next section.

1.2 SYSTEMS CONCEPTS IN OPERATIONS MANAGEMENT

A system may be defined as “as purposeful collection of people, objects and procedures for operating within an environment”. Thus every organisation can be represented as a system consisting of interacting sub-systems. The features of a system are that these have inputs and outputs. The basic process of the system converts the resource inputs into some useful form of outputs. Of course, depending upon the efficiency of the conversion process we may have undesirable outputs too-such as pollution, scrap or wastage, rejections, loss of human life (in a hospital) etc. Using the

generalised concept of production (which includes services) we can call such systems as production systems.

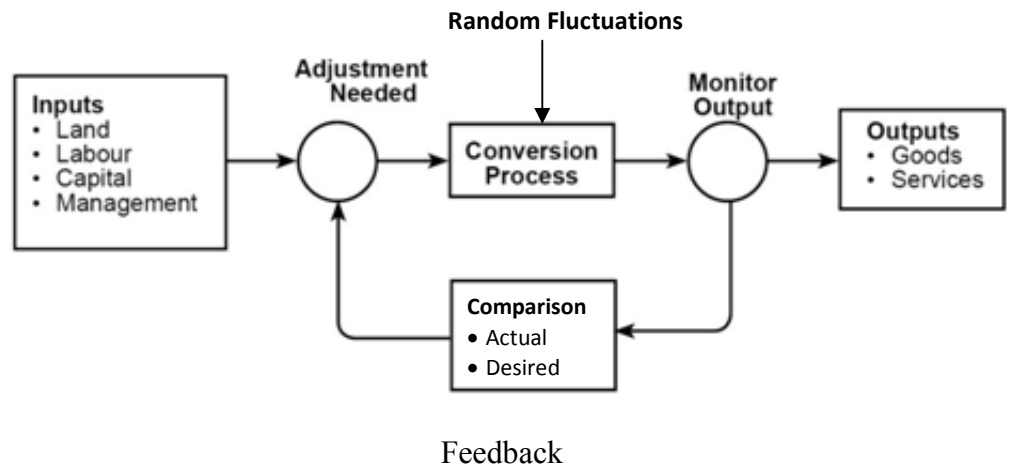


Figure: I Conceptual Model of A Production/Operations System

Figure I describes a generalized concept of production system. It takes resource inputs and processes them to produce useful outputs in the form of goods or services

Inputs and Outputs

Inputs to the system may be labour, material, equipment (machines), facilities, energy, information and technology. Thus machines and materials, which constitute the main focus of this book are the resource inputs required by the production system. Other inputs to operating system can be customers in a bank, patients in a hospital, commuters to a public transport system, files and papers to an office situation, and programmes to be run in a computer centre etc.

Productivity of Conversion Process

Now we come to the main question of how we know that we are managing our system operations well. This concerns the efficiency with which we are converting the inputs into outputs. This conversion efficiency can be roughly gauged by the ratio of output/input; a term which is generally known as 'productivity' of the system. It is obvious that productivity can be improved by maximising the desirable form of outputs from the system for a given level of resource inputs or alternatively by requiring a minimum amount of resource inputs for a given level of output from the system.

Thus

$$\text{Productivity (P)} = \frac{\text{Output (O)}}{\text{Inputs (I)}}$$

Management of production systems is essentially concerned with the management for productivity. An alternate way of looking at the concept of productivity is to look at the amount of waste generated in the system, then

productivity can be improved by reducing wastefulness (or wastivity) of the system.

Thus a simple way to look at the productivity improvement is to attack wastes of all types of resources – materials, labour, capacity of machines, time, space, capital etc.

If you look a bit deeper into what is happening inside the conversion system – you could find only two mutually exclusive things happening. Either, the resources are being processed (operation) taking it nearer to the completion stage or nothing useful is happening to the resource inputs. For example materials may be waiting in the form of inventory in stores, waiting to be loaded on the machine. Job orders may be waiting to be processed. In a hospital a patient may be waiting to be attended to etc. All these forms of waiting delays in inventories are non-productive events and any drive to improve productivity must aim at eliminating or at least reducing such idle time, waiting etc. Thus if you wish to improve your system operations, try to attack such non-productive elements in the total throughput time of the entity in the system.

Differences between Services and Goods Production

A clear line of demarcation between the products and the services is much less apparent. Almost all purchases of consumer products involve services as well as the product itself. If you buy an automobile, you not only buy the product, but also take the guarantee of the parts and the numbers of servicing of the vehicle. Similarly a fast food operation delivers physical products (dosa, idli, waada and samber etc) along with the service. Hospital care involves medication bandages, X-ray film and so on. Most productive systems provide a bundle of products and services and an operations management recognize both aspects of the outputs of the system. Examples of manufacturing system are production of cement, paper, coal, textile, automobile, TV, machine tools and furniture etc, while the service system includes telephone exchange, post office, bank, hospital and cinema hall etc. However there are certain differences between services and goods production.

- 1) Services may provide intangible, psychological benefits that are not easily measured by the senses of touch, smell, sight, sound and taste while goods are the physical outputs of a process. To put it in another way (as in the word of Richard B. Chase), *“a service is something that if you drop it on your feet it won't hurt you”*. Products are tangible things that we can carry away with us where as services are intangible and perishable that are consumed in the process of their production. Output from service system is non-inventoriable. You cannot generally produce to stock the ‘aggregate of services’ (no inventory is accumulated). While for a product (a tangible item), it will have a closing stock at the end of an accounting year, whereas there is nothing like closing stock for a

range of services. Services cannot be counted, stocked, weighed and verified.

- 2) A person being served often participates in the productive process, as by providing part of the labour in self-service systems. Sometimes there is a great deal of contact with the client or customer in the service system and human contact is almost the essence of many such services. In product systems, there are very little, if any, contact between the producers and users of the product, and that is left to distribution and retailing, when customers purchase an item or have it serviced.
- 3) There is a high degree of heterogeneity in the aspects of the services and no two services are exactly alike. A dentist attending to two consecutive patients having identical ailments may provide more or less same type of service, however the two patients may have different perceptions of the quality of service and may have different satisfaction levels. Moreover the time spent by the dentist in both the cases could be highly variable.

Demand for services is often extremely variable on a short term basis, that is weekly, daily or even hourly variations are common whereas the demand for products usually tends to be on a weekly, monthly or seasonal basis.

- 4) Simultaneous production and consumption- More often, service happens in the presence of customer and the customer may also be involved at the time of the service. In the above example (3) the dentist and the patients are there in the service together to produce and consume the service of dental care. Similar is the case of education, entertainment, travel, tourism and hotel services. On the other hand, in the case of manufacturing, most goods are produced at some point of time and distributed to customers later on.
- 5) Service operations may be labour-intensive. The work of typing of a typist on a single foolscap page may cost you Rs 20 or so while the cost of one sheet of paper is 20 paise only. For the service of a facial in a beauty-parlour or at home you may spend around 500 or so with only Rs 5 worth of cream on your face and the ornamental work of embroidery on a piece of cloth worth Rs 10 may amount to as high as Rs 1000 or even more.
- 6) Taking advantage of the process of mechanization and automation, markets of products can be regional, national or even international but as because services cannot be shipped to distant places, the service systems ordinarily shrink to the local markets only. Also the location of a service operation is dictated by the location of the users of the area. No barber can even imagine to open a hair cutting salon near the Golden Temple in the holy city of Amritsar of Sikh devotees. Likewise you cannot sell non-vegetarian dishes like fish, meat and chicken in and around the pilgrim

places of Rishikesh and Hardwar and rain-coats outlets can never be thought to be established in the desert city of Jaisalmer (Rajasthan).

- 7) Service (the intangible good) once rendered to the customer can never be taken back in case the customer does not like the quality of service. Can the length of the hairs be restored on your head incase you do not like the *fashion* of hair-cut by the salon-barber or if a massager does not give you the exact quality of massaging you would like to have on your legs, hands and back, can he ever *undo* it? On the other hand, a tangible product if not accepted in quality of workmanship by a buyer (say a dot pen or calculator), it can be returned back to the seller or replaced by a better piece of identical product.

1.3 OBJECTIVES IN OPERATIONS MANAGEMENT

Every system (or organisation) has a purpose, certain objectives and goals to achieve. Since the objectives of an organisation have hierarchical structure, sub-goals lead to accomplishment of goals which contribute to the achievement of objectives and eventually the purpose or mission of an organisation. It is very important that these objectives should be unambiguously identified, properly structured and explicitly stated.

In general terms, the objectives of an organisation may be to produce the goods/or services in required quantities and of quality as per schedule and at a **minimum cost**. Thus quantity, quality and time schedule are the objectives that determine the extent of customer satisfaction. If an organisation can provide for these at a minimum cost then the 'value' of goods created or services rendered enhances and that is the only way to remain competitive. Thus various objectives can be grouped as performance objectives and cost objectives.

Performance Objectives

The performance objectives may include:

- a) **Efficiency** or productivity as output per unit of input.
- b) **Effectiveness**: It concerns whether a right set of outputs is being produced. Where efficiency may refer to 'doing things right', effectiveness may mean 'doing the right things'.
- c) **Quality**: Quality is the extent to which a product or service satisfies the customer needs. The output has to conform to quality specifications laid down before it can be accepted.
- d) **Lead times**: Manufacturing lead time or throughput time is the time elapsed in the conversion process. Minimisation of idle time, delays, waiting etc. will reduce throughput time.
- e) **Capacity utilization**: Percentage utilization of manpower, machines etc.

- f) **Flexibility:** If the conversion process has the flexibility of producing a combination of outputs, it is possible to satisfy a variety of customer needs.

Cost Objectives

Attaining high degree of customer satisfaction on performance front must be coupled with lower cost of producing the goods or rendering a service. Thus cost minimisation is an important systems objective. Costs can be explicit (visible) or implicit (hidden or invisible). These could be tangible in economic terms or intangible in social cost terms-such as delayed supplies, customer complaints etc. While managing production systems we must consider both the visible and invisible, tangible and intangible costs. Some examples of these costs are:

a) Explicit (visible) costs:

- Material cost
- Direct and indirect labour cost
- Scrap/rework cost
- Maintenance cost

b) Implicit (invisible/hidden) costs:

- Cost of carrying inventory
- Cost of stockouts, shortages, back-logging, lost sales
- Cost of delayed deliveries
- Cost of material handling
- Cost of inspection
- Cost of grievances, dissatisfaction
- Downtime costs
- Opportunity costs

For the purpose of managerial decision-making, we should consider the total relevant systems costs including visible and invisible. A longer term cost implications rather than only short-term will help in arriving at better decisions.

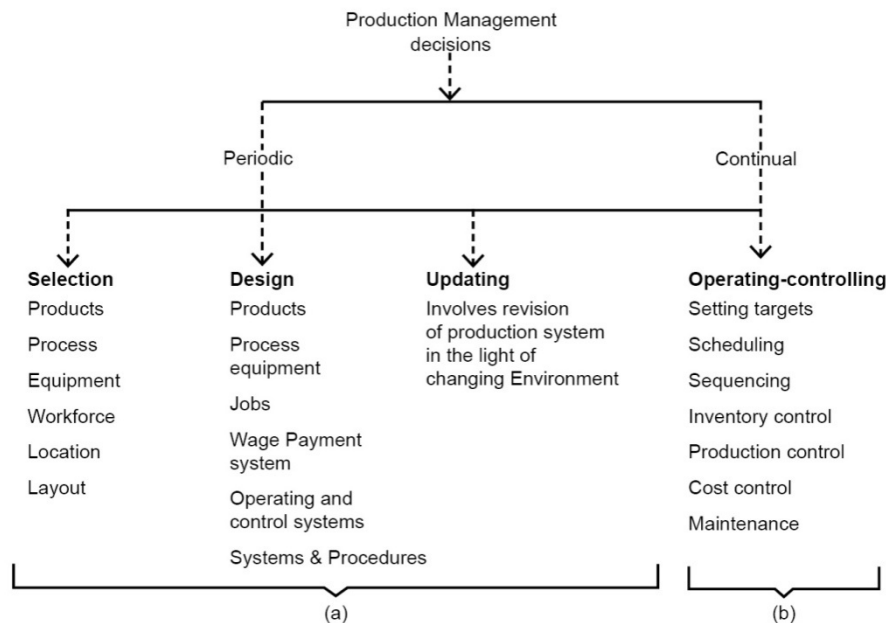
1.4 DECISIONS OF PRODUCTION AND OPERATIONS MANAGEMENT

The Process of Management : Operations management can be essentially considered as a process of planning, organizing, directing and control. There are different ways in which the production management functions can be grouped for the sake of discussion. These are summarized as **Classification of Decisions :** **The first way** to group these decisions are :-

- a) **Periodic decisions** which include selection, design and updating of resources, structures, systems and procedures.
- b) **Continual decisions** which are required in day-to-day operation and control of production systems.

These decisions are shown below in tabular form.

Figure II: A classification of Production Management Decisions



Source: Chase, R.B. and N.J. Aquilano, 1973. Production and Operations Management. A Life-cycle Approach, Richard D. Irwin: Homewood.

Yet another way of looking at these decisions may be :

- i) Planning and Design of Production Systems
- ii) Operations and Control of Production Systems

The major topics covered in this block will be grouped as per the above-mentioned classification.

A third way to group these could be : (Functions of Production and Operations Management)

- a) **Planning Decisions** :Planning the conversion systems, planning the use of the conversion systems. Planning involves aims and objectives and action to achieve them in the organization.
- b) **Organising Decisions** :Identifying and grouping work to be done for conversion, structuring of operations, staffing, Job and work design, Production/Operations standards, Payment systems etc.
- c) **Directing and Controlling Decisions** : Monitoring and control of conversion system in respect of

- (i) Quantity
- (ii) Quality

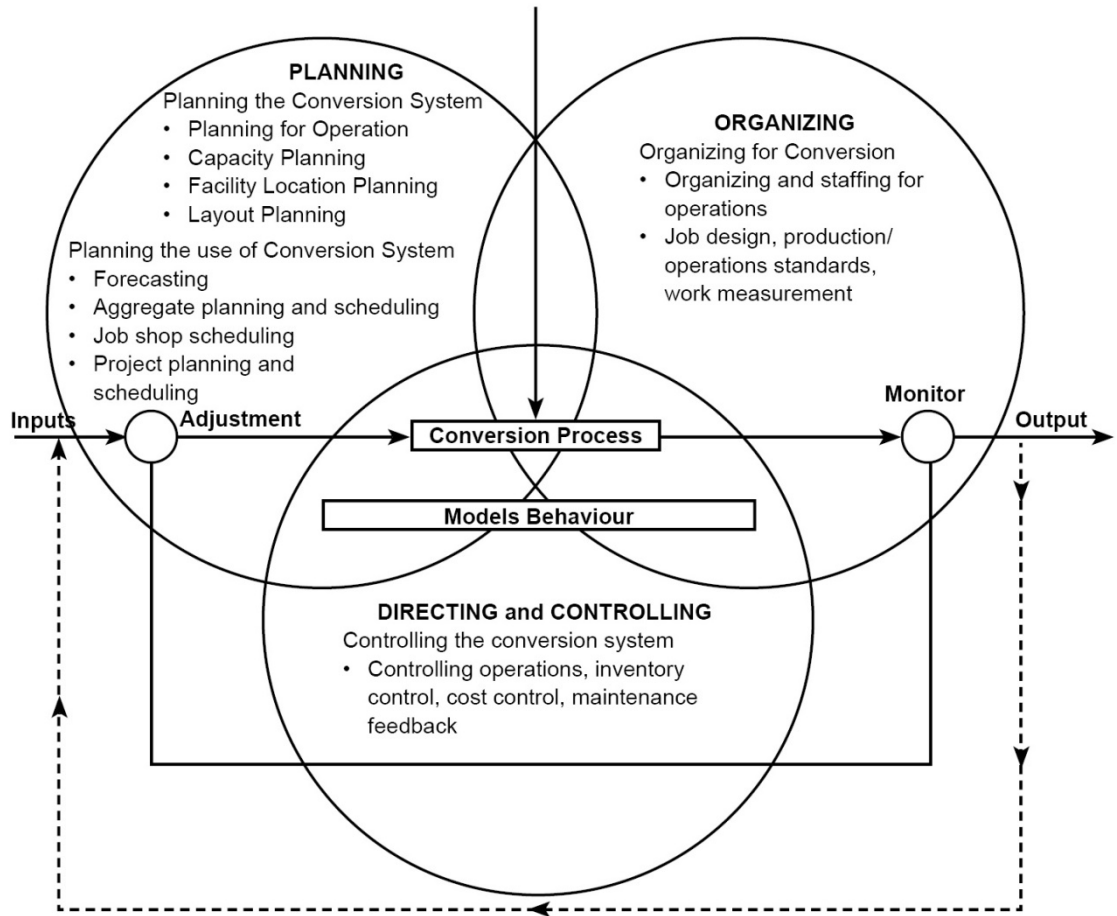
(Directing is concerned with carrying out the desired plans related with the target and controlling is exercising

- (iii) Time
- (iv) Inventory
- (v) Cost
- (vi) Maintenance

commands for achieving objectives of the enterprise.)

A schematic diagram of the above is shown in Fig. III It will be noted that some of the areas of decision are overlapping in nature.

Figure III: A Framework of Planning, Organizing and Control Decisions in Production Systems



Source: Adam Jr., E.E. and R.J. Ebert, 1978. Production and Operations Managerial Concepts: Models and behavior, Prentice-Hall-Inc., Englewood-Cliffs.

Strategic (Long-Term) and tactical (Intermediate-Term) Desisions

A strategic decision is one which has a long-term impact, influences a larger part of the system and “once implemented” cannot be undone easily. These decisions essentially deal with Design and Planning (long term and intermediate term) aspects. Some examples of these decisions are :

- a) **Product Selection and Planning** :It is a crucial decision as to what products and services are to be offered. A careful evaluation of product/service alternatives on the multiple objective basis can help to select the right product. In order to do away with the unnecessary

features and in creating a good design, the techniques of value engineering can be immensely helpful.

- b) **Process Selection and Planning** : Concerning choice of technology, equipment and machinery, to select the optimal process under the circumstances is an important decision. The process planning includes careful detailing of the processes of resource conversion along with their sequence. The aspects of mechanisation and automation are also to be kept in view.
- c) **Facilities Location** : A poor location of production system or its facilities may spell operating disadvantages for all times to come. It is important therefore to select a right location in order to minimise the total production plus distribution cost. Such a decision obviously calls for evaluation of location alternatives against multiplicity of relevant factors considering their relative importance for the system under consideration.
- d) **Facility Layout and Material Handling** : In order to facilitate material flow, reduce handling cost, delays and congestion provide good housekeeping and to facilitate coordination from one department (activity centre) to another, facility layout planning problems are very important. For integrating the actual factors of production, a detailed layout blueprint has to be prepared depending on the nature of the production system. Proper choice of the material handling equipments such as fork-life truck, conveyors, jib crane, electric hoist etc. is a related decision of layout planning. In order to help in layout planning for process based layouts, there are a number of computer packages developed such as Computerised Relative Allocation of Facilities Techniques (CRAFT), Computerised Relationship Layout Planning (CORELAP) and Automated Layout Design Programme (ALDEP). Newer techniques, particularly computer based are significantly altering the traditional concept in layout planning. More recently the concept of Group Technology (GT), Cellular Manufacturing System (CMS) and Flexible Manufacturing System (FMS) have influenced the layout planning and material handling policies significantly.
- e) **Capacity Planning** : Capacity is the maximum available amount of output of the conversion process over some specified span. Capacity planning may be over short-term as well as the long-term basis. In service system, the concept of capacity and hence capacity planning is slightly more difficult problem. Long-term capacity planning includes expansion and contraction of major facilities required in conversion process, determination of economics of multiple-shift operation etc. Break-even analysis is a valuable tool for capacity planning alongwith learning curves, linear programming and decision trees.

Operation (Short-Term) Decisions :Operational level decisions deal with short-term planning and control problems. Some of these are the following :

- a) **Production Planning, Scheduling and Control** :In operation scheduling, we determine the optimal schedule and sequence of operations, economic batch quantity (EBQ), machine assignment and dispatching priorities for sequencing. Production control is a complementary activity to production planning and involves follow-up of the production plans.
- b) **Inventory Planning and Control** : It deals with determination of optimal inventory levels at raw material, in-process and finished goods stages of a production system. The quantity of purchase and the time to purchase are two typical decisions involving inventories. Material requirement planning (MRP) is an important upcoming concept in such a situation.
- c) **Quality Assurance** : We must ensure that whatever product or service is produced, it satisfies the quality requirement of the customers at the lowest cost which is known as the “quality assurance” . Setting standards of quality, control of quality of products and services and value engineering considerations are the related issues of quality assurance.
- d) **Work and Job Design** : These are problems concerning the following :
 - i) Design of work methods
 - ii) Systems and procedures
 - iii) Method improvement
 - iv) Elimination of avoidable delays
 - v) Work measurement
 - vi) Work place layout
 - vii) Ergonomic considerations in job design
 - viii) Work and job restructuring
 - ix) Job enlargement
 - x) Design and operation of wage incentives
- e) **Maintenance and Replacement** : These includes decision regarding :
 - i) Optimal policies for preventive, routine and breakdown maintenance of machines
 - ii) Repair policies and replacement decisions
 - iii) Maintenance of manpower crew
 - iv) Scheduling and sequencing of repair jobs
 - v) Preventive replacement
 - vi) Condition monitoring of the equipment and machines

Maintenance is extremely crucial problem area because it is only through a very effective maintenance management, we can improve

capacity utilization and keep our plant and machinery productive and available for use, particularly in a developing country like India.

- f) **Cost Reduction and Control :** The role of cost reduction for an on-going production system is very important because through effective control of total cost of production, we can offer more competitive products and services. Value engineering is a prominent technique available for cost reduction. Concepts like standard costing and budgetary control help in monitoring and controlling the costs of labour and material etc. and suggest appropriate follow-up action to keep these costs within limits.

Monitoring and Feedback Control : The actual realization of objectives in a system may not be as planned for various reasons. It is therefore, very important to monitor the actual performance by measuring the actual output or some performance indicators. For the control of quantity, quality, time, inventory or cost, the following are the basic elements of monitoring and feedback control :

- i) Establish standards of performance or output
- ii) Measure actual performance
- iii) Compare the difference between the actual and planned
- iv) Take appropriate remedial actions by changing inputs, revising plans, changing priorities and expediting the progress etc.

Without monitoring and control, planning may not be effective and without planning, control may not be effective. Thus planning and control are two sides of the same coin. But in the design of the control system, we should keep in mind the cost-benefit aspect of control because if cost of control exceeds its benefits, it becomes counter-productive. Thus selective control may be employed following the Pareto's principle.

Need for Updating and Review of Decisions: In the planning of our production and operations system, the process assumes certain external and internal environment of work. In a dynamic system, the changes in the environmental parameters may make our previous decisions out of date. In light of this, we need to review, revise and update our decisions by switching over to group technology and we may add or delete our product line and reassess the product design on the basis of newer types of material and feedback from our customers.

1.5 TYPES OF PRODUCTION SYSTEMS

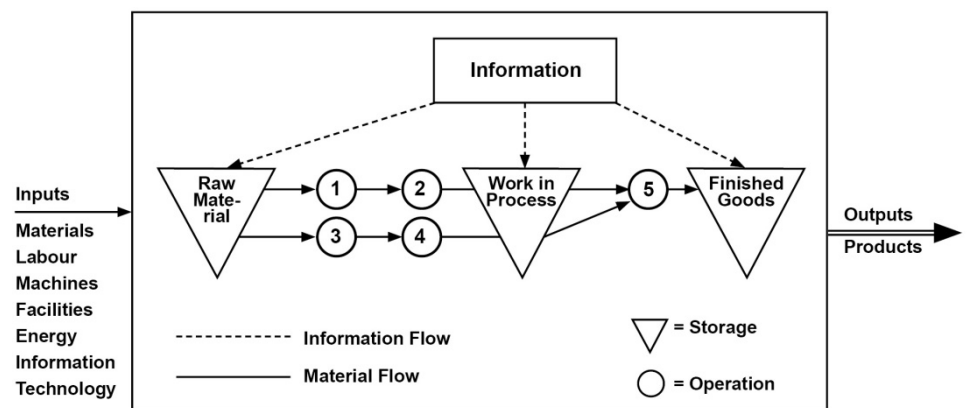
Looking from a different point of view, the entire problem of the production/operations management can be visualized as that of managing the 'material' flow into, through, and out of the production system. If we try to detail out the flow characteristics inside the conversion systems, we shall find that some systems have very smooth and streamlined flow; some others may have more complex flow characteristics. In general, the more complex the

flow characteristics inside the system, the more difficult it becomes to manage the system. On the basis of material flow characteristics, the production system can be grouped into the following four categories:

- A) Mass production or flow line production system
- B) Batch production system
- C) Job shop production
- D) Unit manufacturing or projects

The main focus of production management problems will therefore depend upon the type of the system. Problems which are very crucial for mass production may not be relevant for batch production and vice-versa. It is therefore very important to identify the type of systems we are managing and then focus on main problems of planning and control relevant to that system. A brief description of these problems are given in the following sub-sections. Figure IV shows the flow characteristics of a typical production system.

Figure: IV Material Flow characteristics of A Typical Production Process



Source: Menipaz, E. 1984. Essentials of production and Operations Management, Prentice-Hall Inc Englewood-Cliffs.

A) Mass Production or Flow Line Production Systems

Continuous flow production (Mass Production) situations are those where the facilities are standardised as to routing and flow since inputs are standardised and therefore a standard set of processes and sequence of processes can be adopted.

These systems have simplest flow characteristics constituting straight line flow. Facilities are arranged according to sequence of operations where the output of one stage becomes input to the next stage. The whole system is cascaded.

Major Production management problems in mass production systems are-balancing of production/assembly lines, machine maintenance and raw materials supply. In a production line consists of the series of production centres, if workload is unbalanced, then the most bottle-necked production

stage will govern the whole output rate. This will result in increased throughput time and poor capacity utilisation thus contributing to low productivity. Hence a production or assembly line should be designed such that its workload is as evenly balanced as possible. Maintenance becomes important because if any production stage is under breakdown it will block the whole line unless quickly restored back into operational effectiveness. Raw material to first stage is important to avoid shortage and subsequent starvation of the whole line.

There are methods and techniques available to attend to the above mentioned problem areas. Some of these will be discussed in a later unit on operations planning and control aspect of mass production system.

Characteristics. The main features of continuous production system are as follows:

- i) The volume of output is generally large (mass production), and goods are produced in anticipation of demand.
- ii) The product design, the conversion process and the operations sequence are standardised, i.e., identical products are produced.
- iii) Machines and equipment are arranged according to product layout pattern.
- iv) Special purpose automatic machines are used to perform standardised operations.
- v) Machine capacities are balanced so that materials are fed at one end of the process and finished product is received at the other end.
- vi) Fixed path material handling equipment is used due to the predetermined sequence of operations.

Merits and Limitations : Continuous production offers the following advantages

- a) The quality of output is kept uniform because each stage develops skill through repetition of work.
- b) Any delay at any stage is automatically detected. As a result there is automatic control of time and the direct labour contact is reduced.
- c) Work-in-progress is minimum on account of sequence balancing.
- d) Handling of materials is reduced due to the set pattern of production line.
- e) Control over materials, costs and output is simplified. The repetitive nature of processes make production control easier.
- f) Overhead cost per unit is reduced due to spreading of large fixed costs of specialised equipments over a large volume of output.
- g) There is quick return on capital employed.

Continuous system, however, is very rigid and if there is fault in one operation, the entire process is disturbed. Due to continuous flow, it becomes necessary to avoid piling up of work or any blockage on the line. Unless the fault is cleared immediately it will force the preceding as well as the subsequent stages to be stopped.

Suitability. Continuous system is best suited to organisations which intend to produce a limited variety of products on a large scale. The heavy fixed costs of specialised equipments that are utilized for operating at low cost per unit can be distributed over a high volume of output.

Electronics, electricals, pins, clips, buttons, automobiles, bicycles and container industries are some of the examples of mass production.

B)Batch Production System

Batch production has been defined as “the manufacture of a product in small or large batches or lots at intervals by a series of operations, each operation being carried out on the whole batch before any subsequent operation is performed.”

If a variety of products are made with relatively small volume of production, it may not be possible to layout a separate line for each product. In such cases, batch production concept is adopted when a product is made in a certain quantity called as ‘batch quantity’ on a machine, and after a while it is discontinued and another product is scheduled in a certain batch quantity. Thus various products get completed for the share of a machine. The machines are for general purposes. Material flow in such systems is more complex than in mass production systems. Accordingly, the planning and control aspects are relatively more difficult. Some prominent problem areas are optimal layout planning for the production system, aggregate production planning to absorb demand fluctuations economically, Machine-job allocation problem, determination of economic batch quantity and scheduling and sequencing of operations.

Characteristics. The essential features of batch production are given below:

- i) A large variety of products is manufactured in lots or batches
- ii) Both general purpose machines (for producing parts) and special purpose machines (for assembling the parts) are used
- iii) Variable path material handling equipment is used
- iv) Machines and equipment are arranged according to the sequence of operations, i.e., process layout is followed.

Merits and Limitations. Batch production combines the features of both flow production and job production types. Some degree of specialisation is possible and capital investment is comparatively low. But work-in-progress inventory is high and large storage space is required. Due to frequent changes

in product design no standard sequence of operations can be used. Machine set-ups and tooling arrangements have to be changed frequently.

The main problem in batch production is the idle time between one operation and the other. The work has to wait until a particular operation is carried out on the whole batch.

Suitability. Batch production is applied when either the volume of output increases resulting in some repetitiveness or the market demand is not uniform throughout the year. In the latter case occasional discontinuity in production occurs as switching to other product becomes necessary.

Industrial blowers, motors, book printing, export production, drugs and machine tools etc. are common examples of batch production.

C) Job Shop Production.

Job shop production involves the manufacturing of a single complete unit with the use of a group of operators and processes as per the customer's order. A job shop does not have its own standard product and accepts whatever customer orders come in. Thus it is essentially a group of facilities and processes a wide variety of customer orders in varying batch sizes. Each order may be a new order requiring process planning, tooling and sequencing. Material flow in job shop like situation is quite complex. A dynamic job shop where even customer orders come in a random fashion is a very difficult system to analyse at least from the point of view of production, planning and control. The main problem is dispatching priority rule to determine the sequence in which various waiting job orders are to be processed on manufacturing facilities. For example, a production manager may sequence the job orders on the basis of the short processing time (SPT) rule. The job requiring smallest operation time gets top most priority in order-scheduling. From analytical point of view a job shop can be treated as a network of queues and the waiting line models or simulation techniques can be used to analyse it.

Characteristics. The main characteristics of job shop production are as follows:

- i) The product manufactured is custom-made or non-standardised.
- ii) Machines and equipment are arranged or assembled at one place.
- iii) A wide range of general purpose machines like grinder, drill, press and shaper etc., is used.
- iv) Volume of output is generally small.
- v) Variable path materials handling equipments are used.

Merits and Limitations. Job production involves comparatively small investment in machinery and equipment. It is flexible and can be adapted

easily to changes in product design. A fault in one operation does not result into complete stoppage of the entire process.

Job shop manufacturing is the most complex system of production. For instance, in building a model, thousands of individual parts must be fabricated and assembled. A complex schedule of activities is required to ensure smooth flow of work without any bottlenecks. Many parts require operation time on the same machines even though the operations in the manufacturing cycle take place at different points of time. Optimum machine loading is, therefore, a very difficult problem.

Raw materials and work-in-progress inventories are high due to uneven and irregular flow of work. Therefore, large storage space is required and material handling costs are high. Highly skilled machine operators are required for the efficient performance of setting up and operating tasks. Work loads are unbalanced. Labour and equipment must be flexible to accommodate the continuously changing production. There is often inefficient utilisation of labour and plant. Speed of work is slow and unit costs are high.

Suitability. Job shop production is applicable where custom-made products are to be produced on a small scale. Typical examples of jobs production are: special projects, models, prototypes, custom clothing, jigs and fixtures, repair in existing machinery, repair and overhauling of automobile vehicles and construction equipments subassemblies etc.

D) Unit Manufacture or Projects

Project is defined as “an endeavor” with specific objective to be met within the prescribed time and cost limitations that has been assigned for execution.

Suppose we want to make a ship. Obviously due to large size of the product, the entire concept of material flow should change. In the previous three cases the manpower and facilities were fixed and product (or material) was moving from place to place. Here product remains fixed and manpower/facilities put work on it in some chosen sequence. Since such products are not made in large number and have long throughput time, we can treat each product as a project. Thus project planning, scheduling and monitoring techniques based on network models such as PERT/CPM can be used for planning and control of such production systems.

Characteristics.

- i) Project has a definite start and finish i.e. it is executed in a time bound schedule.
- ii) It needs resources and skills of diversified nature.
- iii) It has a definite and definable goals or end results that can be defined in terms of costs schedule and performance requirements.

iv) Project passes through distinct activities, which constitute Project Life Cycle

Merits and Limitations. Planning and scheduling of activities and procurement function are critical to the success of the project. Inventory is mainly concentrated in product itself and material always flow in the same direction. Reducing inventory simply means shortening the delivery time and is equivalent of using equipment to the maximum of its capacity.

Unit manufacture or project is one-off job, which may not repeat in exactly the same manner.

Suitability. Suitable for construction, erection work and commissioning of plants.

Typical examples are : ship building, electric power plant, blast furnace, dam construction, machine shop, printing press, turbine and boiler manufacture etc.

1.6 MANAGEMENT OF MATERIALS IN PRODUCTION SYSTEMS

As mentioned previously, problems of production management essentially concern management of material flow into, through and out of the system. This makes materials management a vital subject. Since materials constitute an extremely important and costly resource to a production system. An improvement in materials productivity will lead to overall improvement in systems performance and cost reduction.

Material Management is defined as the grouping of management functions supporting the complete cycle of material flow from the purchase and internal control of work-in-process to the warehousing, shipping and distribution of finished products.

Role of Materials Management

Materials in Indian context constitute more than half the total cost of production in most industries and projects. In some industries 60-70% total production cost is due to materials. This makes materials management the biggest single area having tremendous potential for cost reduction. A well coordinated materials management programme may lead to 15-20% cost reduction.

If inventories are taken as an index of materials management effectiveness, then there is so much that can be done to cut inventories in Indian industries. If inventory is viewed as 'usable but idle resource' then we can also call it a 'necessary evil'. Our materials planning system should be such that we are able to ensure adequate supply of materials to meet anticipated demand pattern with the minimum amount of capital blocked in inventories.

Objectives. The primary objective of a company is to reduce the cost that occurs while buying, storing, handling, transporting and packaging materials. In addition material management has the following objectives :

- i) Maintains steady flow of materials ensuring that production does not get interrupted.
- ii) Adopts cost reduction techniques like MRP and value analysis to manage the total cost required for proper management of materials.
- iii) Provides right materials in the right quantity and right time to ensure the production of high quality product.
- iv) Implements scientific inventory control techniques to reduce investment.
- v) Maintains records of stores and purchase etc.
- vi) Preserves stocks so that any loss of materials caused due to deterioration, pilferage and obsolescence can be kept at the minimum.
- vii) Improves producer-consumer relationship by producing high quality product.
- viii) Minimises wastage of materials and therefore reduces operating costs.
- ix) Disposes surplus materials, metal cuttings and chips to economise on cost.

Need for Integrated Approach to Materials Management

To be most effective, our desire to maximize materials productivity must aim at getting most out of every rupee invested in materials. This calls for a well coordinated and integrated approach towards various problem areas involving decision-making with respect to materials. It can be seen for example that the inventory in the system can be lessened by reducing uncertainties in demand and supply, by reducing procurement lead time, by reducing excessive material varieties through standardisation, codification and variety reduction programmes. Thus development of reliable sources of supplies to have 'just in time' supply will reduce inventories substantially.

Other important areas to improve efficiency on materials management front are:

- a) **Value analysis, purchase price analysis :** In this we want to put right kind of material through competitive prices to reduce the material bill. Value analysis aims at getting the required function performed at minimum cost and therefore value analysis technique has a major role in materials related cost reduction.
- b) **Materials handling :** Materials handling provides place (location) utility only. Otherwise it does not add to functional or aesthetic value of materials but is an element of cost. Thus our aim should be to design systems of production and storage to minimise the costs associated with movement and handling of materials.

- c) **Inventory control** :Here we try to plan our procurement actions so that we can get the demand satisfied reasonably well without having to stock (in inventory) too much of materials. This is a very well discussed problem area in literature on materials management.
- d) **Stores management** :Stores function looks after physical custody of materials. By proper planning of layout, storage materials and issuing policies we can ensure faster service so that items demanded by production can be supplied without delay. Avoidance of pilferage, wastage and storage losses are also important aspects of stores management.
- e) **Waste management** : Materials waste must be minimised if not totally eliminated. Waste can also be considered as a barometer of materials productivity. If materials waste is minimum, productivity of materials improves.

An integrated approach to materials management must look at all the above mentioned problem areas in a coordinated manner with a view to maximise materials management effectiveness.

Cost involved in Material Management. Managing materials involves the following costs :

- a) Capital Cost--cost of materials procured paid by the company to the supplier.
- b) Government levies and taxes.
- c) Ordering cost involving the cost of tendering, stationery, postage, inspection, bill payment and delivery that incurred while purchasing materials.
- d) Inventory carrying cost (holding cost) involving cost of storage, record keeping, wages to stores staff and payment of insurance cover for maintaining inventory.
- e) Packaging cost.
- f) Material handling cost.
- g) Shipment cost.

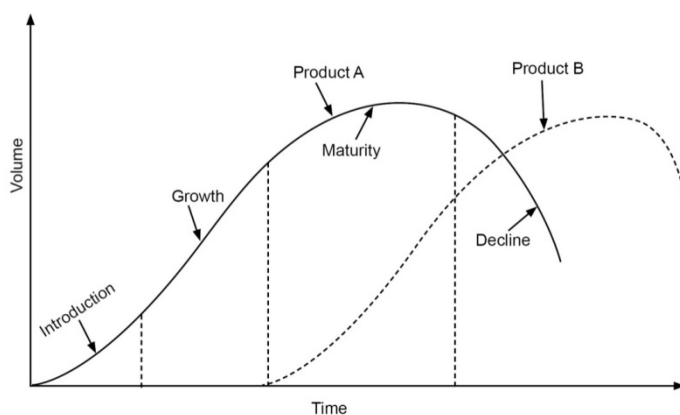


Figure V: Product Life-Cycle

1.7 CONCEPTS IN SYSTEMS LIFE-CYCLE

The life-cycle concept or ‘womb to tomb’ concept draws analogy from living organism. It assumes that every system (product) has a definite life-cycle and it passes through growth, maturity, saturation and decline phases. Figure V shows a typical life-cycle of a product. Similar pattern could exist for the entire production systems. Life-cycle concept enables us to understand various decisions and their inter-dependence in a better perspective. For example if some of the strategic decisions like product selection or plant location, which are made at the early stages of systems life-cycle are wrong, then these would continue to influence day-to-day operations planning and control decisions adversely and no amount of day-to-day effectiveness will be able to undo the damage done by poor decisions at initial stage of life-cycle.

This concept also enables us to be alert to the external environment and start phasing out a dying product and substitute it with a new product well in time

so that continued survival of the organisation can be planned. Figure V shows how introducing new product well in time can cause long-term survival of the organisation even if individual products follow life-cycle pattern. Life span of a product may vary from a few months (such as fashion goods) to a few decades.

Stages in System Life-Cycle

Figure VI shows the eight stages of the system life-cycle along with the associated key decisions to be made at each stage. Some of the initial decisions like product selection, technology selection, location and layout selection are of strategic importance. Once the system has achieved steady state—most on—going organisations we work in are probably at that stage--then most problems of operations management are of tactical or operational nature. Short-term planning and control and cost reduction strategies are the main focus at that stage. The steady state experiences minor perturbations due to external and internal factors. Moderate level changes can be accommodated by updating and revising of the previous decisions. When the system cannot adjust to even major revisions due to extreme changes in external environment, then the systems must come to an end through liquidation or through sale or merger. Termination or phasing out of operations may be sometimes deliberate.

Life-cycle Costing

A very important concept in costing has emerged in recent years--that of life-cycle costing. It says that when we evaluate the cost implications of our decisions we should not consider the short-term cost alone but the entire costs during the life-cycle of the system and equipment. Thus long-term cost repercussion must be examined rather than immediate short-term cost alone.

Such a concept may change our perspectives and seemingly good decisions may not remain attractive if life-cycle costs are computed. For example while purchasing a machine, the short-term cost may mean only initial purchase price and we may be tempted to buy a cheaper equipment or machine. It may however require too much repair, maintenance and operating expenses. If all these costs including initial costs are compared during the life-cycle of the machine, we may find that an expensive machine with very little maintenance, repair and operating cost may be a preferred alternative over initially inexpensive but 'costly-to-maintain' machine.

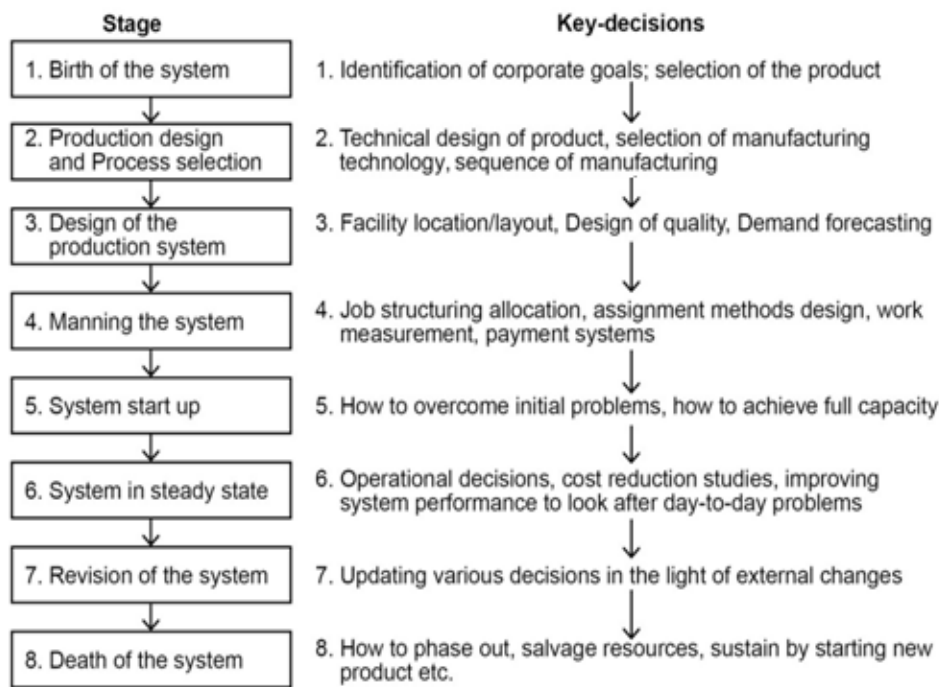


Figure VI: Stages of Life-cycle and key-decisions involved

Source: Chase, R.B. and N.J. Aquilano, 1973. Production and Operations Management: A Life-Cycle Approach, Richard D. Irwin: Homewood

Thus while making important decisions regarding design and planning aspects of production systems we should consider life-cycle costs. These could even be converted to present values by discounted cash flow techniques, accounting for the time value of money.

1.8 ROLE OF SCIENTIFIC METHODS IN OPERATIONS MANAGEMENT

Methods and techniques of scientific management have tremendous role to play in helping us to make rational and logical decisions in the context of production and operations management. Through scientific methods, tools and techniques of industrial engineering and operations research along with **behavioural science** we can look at all facets of the problems and evaluate the consequences of our actions before arriving at a decision. These techniques thus reinforce the subjective or intuitive judgement and contribute to better management.

The Role of Industrial Engineering

Indian Institution of Industrial Engineering (IIIE) has adopted the following definition of Industrial Engineering:

“Industrial Engineering is concerned with the design, improvement and installation of integrated systems of men, materials and equipment. It draws upon specialised knowledge and skills in mathematical, physical and social sciences together with the principles and methods of engineering analysis and design to specify, predict and evaluate the results to be obtained from such systems.”

It can therefore be seen that industrial engineers are designers of management systems and industrial engineering approach integrates various approaches such as operations research, systems analysis, behavioural science etc. towards the integrated design of organisations. In this book many industrial engineering techniques will be used in various units which helps us in better management of production systems.

The Role of Models

Models are representations of systems with a view to explain certain aspects of system's behavior. Generally a mathematical model is preferred in decision-making because it tries to explain system's objectives and function in terms of decision variables subject to our control as well as non-controllable parameters due to environment or resource constraints etc. Thus a simplified form of a model is:

$$E = f(x_j, y_i)$$

Where E= Measure of effectiveness or objective function

X_j = Controllable (decision) variable, $j=1 \dots n$

Y_i = Non-controllable parameter, $i = 1 \dots m$

Thus a model provides us a cause-effect relationship so that we can evaluate our alternative courses of action on the basis of our objectives and choose an optimal (best under the circumstances) strategy to maximize our effectiveness. Thus models provide a valuable tool to compare our options and thus improve the quality of decisions and provide us a better insight into our decision process. However, it must be noted that models are a means to achieve an end (better decisions) and not an end itself. We must choose a simple, valid and logical model of the decision situation. A large number of model based techniques have been developed in the subject called 'Operations Research' (OR) which help is mathematical conceptualization of many decision-making problems relevant to production/operations management. Some very versatile and powerful techniques like linear programming, queuing theory and simulation have been applied extensively to study various problem areas in production management. Some of these will be described, though briefly, in appropriate units in this book.

The Role of Computers

In a large sized problem, a computer becomes a very efficient tool in problem solving and evaluation of alternatives. A big size linear programming or simulation problem can be efficiently solved on computers. Due to fast developments in computing facilities and application software, many OR models can be implemented via computers. Computers also have tremendous role in management information systems to provide useful, relevant and timely information for planning, monitoring and control of production systems--thus providing decision support through information.

The Role of Behavioural Science

Since people are integral part of our production system, understanding of human behavior is very important so that managers can evaluate the consequences of their actions on human relations, morale, motivation and productivity. Supervisor's relationship with his subordinates, organisation structure, individual and group behaviour, work habits and attitude, incentives, participation in decision-making and performance appraisal systems have impact on worker morale and motivation. Behavioural science provides us some insight on these aspects and therefore has a role to play in production and operations management.

1.9 HISTORICAL DEVELOPMENT OF OPERATIONS MANAGEMENT

Historically speaking, the field of operations management has evolved in a very short span of time. Its roots, however go back to the concept of 'division of labour' advocated by Adam Smith in his book "The Wealth of Nations" in 1776. In 1832, Charles Babbage, a mathematician extended Smith's work by recommending the use of scientific methods for analysing factory problems.

However, the era of scientific management as it is now known started with the work of F.W. Taylor in 1878 who subsequently came to be recognized as the 'Father of Scientific Management'. Taylor is credited with recognizing the potential improvements to be gained from analysing the work content of a job and designing the job for maximum efficiency conducted on the shop floor. It brought about significant and rapid increases in productivity. He explained the four principles of scientific management in the following way:

- a) Development of a science for each element of a man's work thereby replacing the old rule of thumb methods
- b) Selection of the best worker for each task and then training and developing the workman on individual basis.
- c) Dividing for the work between management and the workers to simultaneously obtain both maximum production and high worker wages.

- d) Dividing the work between management and workers so that each is working on what they are most proficient in doing.

Taylor described his management philosophy in a book “The Principles of Scientific Management” published in 1911. This event, more than any other, can be considered as the beginning of the field of Operations Management. The colleagues, contemporaries and followers of Taylor were many and included the following people. Frank Gilbreth and his wife Lillian Gilbreth are recognised for their contributions to motion study. Gilbreth developed the concept of ‘Therbligs’ and ‘Chronocyclegraphs’ for motion study in 1911. Lillian Gilbreth wrote her book ‘The Psychology of Management’ which was one of the earliest works concerning the human factor in organisations. In 1913, Henry Ford developed the concept of mass production and arranged work stations into an assembly line with moving belt. In 1913 also, Henry Gantt made his best known contribution in charting the production schedules using a visual-diagrammatic tool which is popularly known as ‘Gantt-Chart’ and is an effective practical tool even today.

In 1913, Harrington Emerson applied Taylor's ideas to develop organisation structure and suggested the use of experts in organisations to improve efficiency. Wilson developed the concept of Economic Order Quantity (EOQ) in 1928 which is still recognised as the classical work in the scientific analysis of inventory systems and works of subsequent researchers were essentially further refinements of Wilson's lot size formula. In 1931, F.H. Dodge, H.G. Roming and W. Shewhart developed the concept of sampling inspection and published statistical tables. Earlier in 1924, W. Shewhart pioneered the concept of statistical quality control and developed control charts for monitoring the quality of production processes.

In 1933, Elton Mayo conducted his famous experiments at Western Electric's Hawthorne plant looking into human and social aspects of work. This paved the way for the behavioural school of management. Mayo felt that scientific management often emphasised technical skills at the expense of adaptive skills. Some other notable developments in these lines include the concept of ‘managerial grid’ developed by a Robert Blake and Maslow's hierarchy of needs and Douglas McGregor's Theory X and Theory Y in management.

In 1937, L.H.C. Tippet developed the concept of work sampling to gauge the level of machine and manpower utilisation and for setting work standards. In and around 1950 two major developments that influenced operations management were the emergence of techniques of ‘Operations Research’ beyond military context and developments of Value Engineering offered by L.D. Miles. The OR is application of scientific methods to study and devise solutions to managerial problems in decision-making. Using mathematical models and the systems approach OR has helped solve resource allocation, scheduling, processing, inventory, location, layout and control problems. Techniques of value engineering helped in efficiently identifying the unnecessary costs so that products and systems could perform their function

at minimum costs. Developments in computers led to computerised applications of Industrial Engineering and OR techniques to production management problems. Development in MIS and DSS (Decision Support Systems) provided a further fillip to the improvement in operations management. In 1958 the concepts of CPM and PERT were evolved for analysis of large projects and since then a number of network based techniques of project management have been designed.

In the late 1950s scholars and researchers in the field began to generalize the problems and techniques of manufacturing to other production organisations such as petroleum, chemical and other process industries leading to the emergence of the concept of 'production management' as a functional management discipline. In the late 1960s the concept of 'Operations Management' expanded to include the service sectors as well. Only recently the service sector has received as much attention as production sector from the point of view of scientific management of systems operations.

Systems approach taking a holistic (integrated) look at the problems of operating systems emerged in the 1970s which considered the inter-play of various sub-systems in organisations. Developments in the computer simulation of integrated production-inventory systems are some of the current thrusts in modeling of production management problems.

In the more recent past there has been a major thrust on the adoption of Japanese management techniques like the 'just in time (JIT) system' or 'Kanban system' for production scheduling and inventory control and the concepts in quality circles (QC). These concepts have apparently done well in Japanese context but should be cautiously adopted in other situations only if external work environment and work ethos make them appropriate elsewhere too. Other notable developments in recent past have been group technology (GT) or cellular manufacturing systems (CMS), flexible manufacturing systems (FMS) and computer-aided design/manufacturing (CAD/CAM) etc.

Helping the quality movement in the field of operations and managerial practices, came into circulation the technique of total quality management (TQM) during 1980s and 1990s. All operations executives were aware of the quality message put forth by the quality gurus – W. Edwards Deming, Joseph M. Juran and Philip Crosby. The ISO 9000 certification standards formulated by the International Organisation for Standardization played a major role in setting quality standards for global manufacturers.

The recent quick adoption of the Internet and world wide web (www) during the late 1990s and early 2000s has revolutionized our thinking in which we collect information, do shopping and communicate with the rest of the world.

The future of Operations Management looks bright.

1.10 SUMMARY

This unit has attempted to give a general overview of operations management. A systems approach treating each operation as a value addition process has been described. The concept of operations management includes both the production of goods as well as services. Operations as the conversion process have been identified to be central function of virtually every organisation. Value is primarily added to entities by changing them directly in space, in time or in our minds. The important characteristics of conversion process have been identified as its efficiency, effectiveness, quality, lead times, capacity and flexibility. Objectives of operations management may be in terms of customer satisfaction or performance objectives as well as cost objectives.

Various decision areas have been categorised as strategic or operational decisions, periodic or continual decisions and various problem areas have been listed under each group. Management of production systems depends upon the structure of the systems and complexity of material flow and accordingly the production systems can be classified as mass, batch, job shop and project production systems. The characteristics of each of these systems together with the relevant production management problems have been highlighted. Role of materials management becomes crucial as materials are responsible for more than half the total cost of production systems. An integrated approach involving coordinated efforts to attempt various problems of materials management is emphasised. Life-cycle approach to products and systems provides a good insight into the key decisions at every stage and concepts in life-cycle costing provide new perspectives to decision-making. Role of scientific techniques of industrial engineering, operations research together with behavioural science and computers is outlined. A brief unit-wise overview of the plan of the book is given so that the relevance of various units to the common theme of the book can be linked.

Finally, a brief historical profile of the subject from the era of Taylor to modern times including modern Japanese management techniques provides a synoptic view of the growth and development of the subject.

1.11 KEY WORDS

Behavioural science: Systematic study of human behaviour.

Batch production: A production system between mass and job shop. A number of products are made in batches on the manufacturing facility.

Control: A management function aimed at ensuring that actual performance is in accordance with the plans formulated to achieve its objectives.

Conversion process: Transformation of inputs to outputs thereby leading to value addition.

Ergonomics: Branch of technology concerned with the problems of the mutual adjustment between man and his work.

External environment: Comprises external surroundings in which an organization functions and which has an impact on its performance.

Feedback: The process of comparing the actual performance and the planned one in order to initiate action for control purposes.

Inputs: All types of resources required by the conversion process for producing goods or services.

Inventory: Usable but idle resource.

Job shop: Manufacturing of varieties of products in small batch sizes according to customer orders.

Lead time: The time elapsing between placing an order and having the goods in stock ready for use in the manufacturing stage. Also known as delivery lag.

Life-cycle: The cycle of birth-growth-maturity and decline of a product or a system.

Management: The process of planning, organising, directing and control.

Mass production: Making of a single product in very large quantities so that facilities can be arranged according to sequence of operations for the product.

Model: A representation of reality intended to explain some aspect of it.

Monitoring: Process of measuring actual performance or progress of work for the purpose of control.

Operations: The process of changing inputs into outputs. It is a purposeful function vital to virtually all organisations.

Operations research: Application of scientific methods, tools and techniques to the problems of decision-making in order to find optimal solution to problems.

Organising: Allocating human and material resources in appropriate combination to implement action plans. It defines tasks, structures and then allocate resources.

Output: Final product or rendering of a service.

Planning: Determining what is to be achieved, setting goals and identifying means to achieve them.

Production: The process of creating goods and services (synonymous to operation).

Productivity: The efficiency of conversion process expressed as output per unit of input.

Project: A set of tasks having sequential dependence with a definite starting and ending point.

Quality: A composite of characteristics that determines the extent to which a product or service satisfies the customer needs.

Schedule: A time table of production system indicating the time when a particular job will be processed on a particular machine.

Sequence: The order in which waiting jobs are to be processed on a machine or a facility.

Service: A bundle of benefits, some may be tangible and others intangible.

Simulation: A technique which feigns systems on paper or on computer in order to describe system behaviour.

Systems: A purposeful collection of people, objects and procedures for operating within environment.

Strategic decisions: Important decisions having long-term impact.

Value engineering: A systematic procedure to identify and eliminate unnecessary costs to provide equivalent function at the lowest costs.

1.12 SELF-ASSESSMENT EXERCISES

- Q1) Explain the different stages of the product life cycle with suitable diagram. How does this life cycle help in developing the strategies to compete in global market ?
- Q2) What do you mean by an integrated approach to Material Management? Explain.
- Q3) Explain the objectives of Operations Management. How does a service organization fix its performance objectives?
- Q4) Define production/Operations Management (POM) in your own words. Will your definition accommodate both manufacturing and service operations? Justify your answer.
- Q5) Explain with the help of suitable diagram the framework of planning, organizing and control in a production system.
- Q6) What are the major distinctions between a manufacturing enterprise and a service organization? Discuss with suitable examples. Why is it more difficult to increase productivity of a service system as compared to a production system?
- Q7) Discuss about the strategic decisions and operational decisions of the production and operations management.
- Q8) Explain the system concepts in operations management with suitable diagram. What are the undesirable outputs of the system of OM?

- Q9) Describe the various types of production system with appropriate examples.
- Q10) Write a short essay on the historical development of operations management.
- Q11) Consider the following situation:

You have been asked to look into the operations of a company which is in the business of repairing and overhauling automobiles. Current practices have led to an extreme amount of customer dissatisfaction due to very high waiting time, discourteous behaviour of work force with the clients, poor quality of workmanship and high cost of repairing automobiles. As a result the customers have started getting their services elsewhere. The owner is very keen to improve the situation but he finds that his people are not motivated by a spirit of service basically because of poor wages and indifferent supervision. This operation is located in an environmentally alert community and they have also been complaining to the local municipal authorities that the nasty way in which operations are handled and waste water disposed off, is causing a lot of inconvenience in the locality. The owner-manager wants your help in improving the effectiveness of systems operations.

How will you analyse the situation? What further information you may need? Prepare a short working paper outlining your suggestions to improve the systems operations.

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UNIT 2 PRODUCT SELECTION AND PROCESS SELECTION

Objectives

After going through this unit, you should be able to:

- appreciate Product Selection as one of the key strategic decisions of any organisation, learn the concept of productibility and its effect on product selection, identify the various stages involved in the product selection process and have a brief idea of the new product mortality curve.
- know the issues involved in screening a new product idea, identify the trade offs involved in product design, understand the impact of product design on process design, identify the various tradeoffs involved in process selection and know the issues involved in the general transformation process selection procedure.
- learn the four forms of transformation processes-their characteristics, advantages and disadvantages, know about the new technologies that are applicable to the transformation processes, understand the concept of Process Life-cycle, learn the use of break-even analysis in choosing the least cost process and appreciate the need to maintain focus in all production operations.

Structure

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- 1.2 The Product Selection Process
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2.1 INTRODUCTION TO PRODUCT SELECTION

Product selection is a strategic decision consisting of “what product is to be produced – in what form, what features and what number” whereas Process Selection decides about the quality and quantity of the manpower, capital requirement and the choice of processes used for the production.

We have looked at operations as the process of converting inputs into outputs and thereby adding value to some entity. This concept of value addition is very important for effective management of the operations function. Although the 'conversion' takes place inside the organisation, the addition of value occurs only when it is perceived to have been done so by the customers of the product or service in the market place. This concept changes the orientation of an operations manager from totally inward looking to one who is alert to the needs of the customers. As we go on to discuss the strategic decisions in operations management in the next couple of units, this issue will come up again and again and it is not out of place to remind ourselves once more that it is not enough to produce a product or service but it has to be produced so that there is an added value as perceived by the market.

Although we differentiated a product from a service above, this differentiation becomes very hazy and confusing. For example, if we are selling a computer, we are selling a product of course. However, instead of selling the computer if we start leasing it to our customers-what are we selling now-a product or a service? On the other hand, so far as the customer is concerned-he is using the computer exactly in the same manner in both these cases. The difference is only in terms of payment and the legal ownership of the asset. Similarly, even when the computer is sold outright, we are also selling after-sales service and other customer support services along with the computer. Thus, we start seeing that so far as the customer is concerned he is only buying some benefits in all these cases and these benefits are services. Services are bundles of benefits, some of which may be tangible and others intangible, and they may be accompanied by a facilitating good or goods. If there are no accompanying facilitating goods, e.g. getting a haircut, we will refer to these services as pure services.

All outputs of an organisation are services and in this unit we would take a deeper look at output selection. Thus, although we have titled the unit as **product selection**, we would like to pursue it as **output selection** keeping in view the service nature of any organisation that we presented above. In what follows, the term product is thus used in its generic sense and is meant to include services.

A Strategic Decision

Product selection is a strategic decision for any organisation. Such decisions are long term decisions and the organisation commits itself to the

product/products selected for a long time to come. What products to produce--in what form and with what features--is very important because many other decisions--for example, the technology used, the capacity of the productive system, the location of the production facilities, the organisation of the production function, the planning and control systems, etc. are dependent on this. The competitiveness and profitability of a firm depend in part on the design and quality of the products and services that it produces, and on the cost of production. The design of a product or service may make it expensive to produce and a change in design may make it possible to produce the same in a less expensive way. Similarly, one design of a product or service may require large and expensive additions to capacity of some process whereas a change in design may make it possible to produce the same with existing capacity.

Product selection is a strategic decision, thereby involves other functional areas like marketing, research and development and as well also the top management therein. The operations management function provides vital inputs regarding the production of the product or service in these decisions making.

Producibility

The product selection process is a highly integrative process. Thus product function, cost, quality and reliability are some of the inputs to this decision. The producibility of a product/service measures the ease and the speed with which the output can be produced.

The specialised equipment, specialised skills and specialized toolings, facilitate in switching production from one product to another etc. and are thus important factors to assess producibility. It is also important to look at the complete range of products produced because a new product may either use the capacity of processes/sub-processes already established or may require the establishment of capacity of some processes/sub-processes. A family of similar products is much simpler to produce than a family of dissimilar products.

2.2 THE PRODUCT SELECTION PROCESS

Product selection is an ongoing process in any organisation. In fact, as the environment changes, as new technology is developed and as new tastes are formed, the product should benefit from these developments; otherwise what is perceived to have added value today may not be perceived as such tomorrow. For example, jute has been in use as a packing medium for a long time. However, with changes in technology and consumer taste, the same product is no more perceived to have added value and therefore, its demand has reduced.

Product Selection Stages

The process of creating, selecting, developing and designing the output of an organisation is shown in Figure I. We will follow the same sequence in our discussion as well. Output possibilities are generated from many sources:

- From the field itself through market research. This can take the form of consumer surveys, dealer surveys and opinion polls etc.
- From research laboratories. This can be due to a breakthrough achieved by pure research or applied research in developing new knowledge.
- From conscious and formalised attempts to generate new ideas for products or services. These ideas can be generated by using techniques like brainstorming, panel discussions, scenario building and technology forecasting etc.

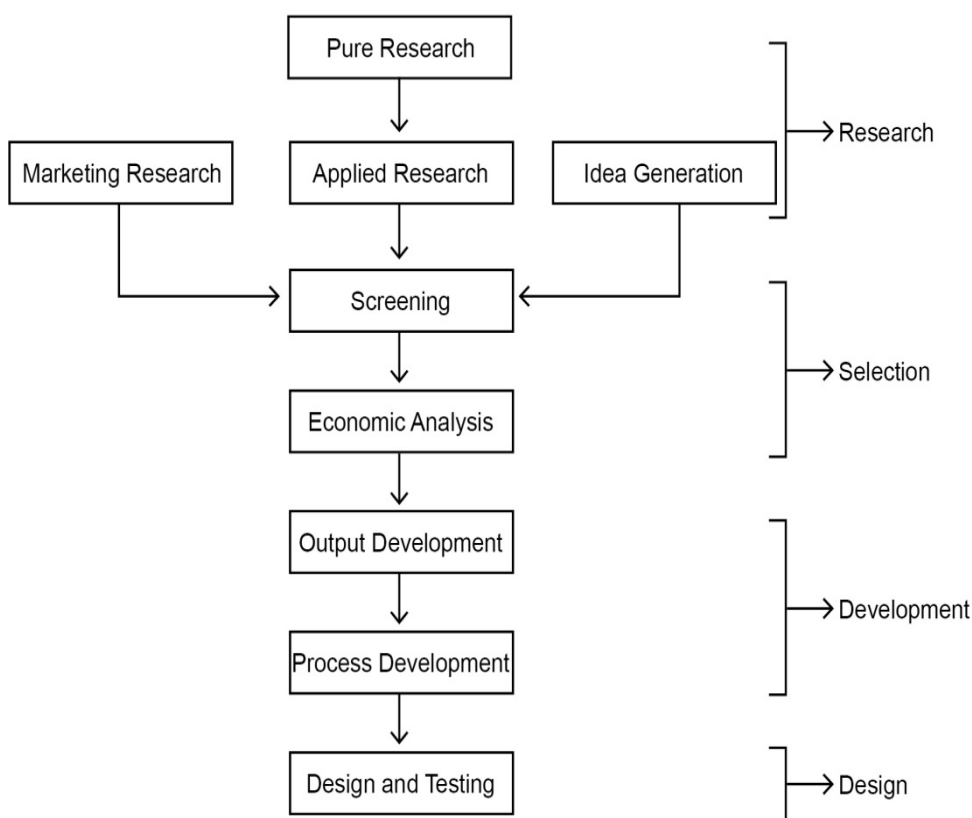


Figure I: Stages of Bringing A New Output to Market

Source: Adapted from Meredith & Gibbs. The Management of Operations, John Wiley, New York.

The output ideas thus generated are then screened where their match with corporate objectives and policies is studied and their market viability is established. A detailed economic analysis is then performed to determine the probable profitability of the product or service. For non-profit organisations, this takes the form of a cost-benefit analysis. This is followed by development of the product or service from a concept to a tangible entity and finally by design and testing.

No Smooth Sequence

Although Figure I depicts product selection as a sequential process where one stage follows another, in reality, the process may not be so smooth as shown. Thus, economic analysis may have to be done after output development if reliable cost estimates are not available at the earlier stage. Similarly, new product features may be added at any of the above stages, thereby initiating a whole new cycle. Finally, as product selection is an ongoing process, there is no finality to other process since as some new product ideas are being processed, still new idea enter the output selection process and this may go on and on. The product selection process therefore ensures a continuous match between what is demanded and what is produced.

In some cases, the production process has also to be designed along with the product or service. This has to be done, for example, when the market viability of the product depends on low cost and so the production process has to be decided along with the product design. Or take the case of another product where it is felt imperative to obtain a large market share right from the initial launch. It may become necessary to establish a large capacity for the production process right from the beginning. The production process has to be designed along with the product in such a case.

New-Idea Mortality Curve

The previous section highlighted the fact that an output possibility has to cross several hurdles before it enters the market as a commercial product or service. The new idea mortality curve presents the same in a graphical manner. Figure II shows the mortality curve for a hypothetical group of fifty chemical product-ideas. Although the product ideas are hypothetical, still the stage-wise mortality as well as the time frame shown is quite indicative. Figure II assumes that after three years of research, fifty potential chemical product-ideas are available for consideration. Initial screening reduces this number to about half and after economic analysis, by the end of year four, the number of potential products decreases to nine. The mortality of ideas continues over time and by the end of five-and-a-half years, at the completion of the product and process development stages, the number has already fallen to about five. Design and testing reduces this further to about three and by the end of construction, market development and commercialisation, just about one successful product is left. Figure II is based on international experience, and situation in India has not been tasted empirically. Thus, the mortality curve should be treated as an indicative proposition in the Indian context.

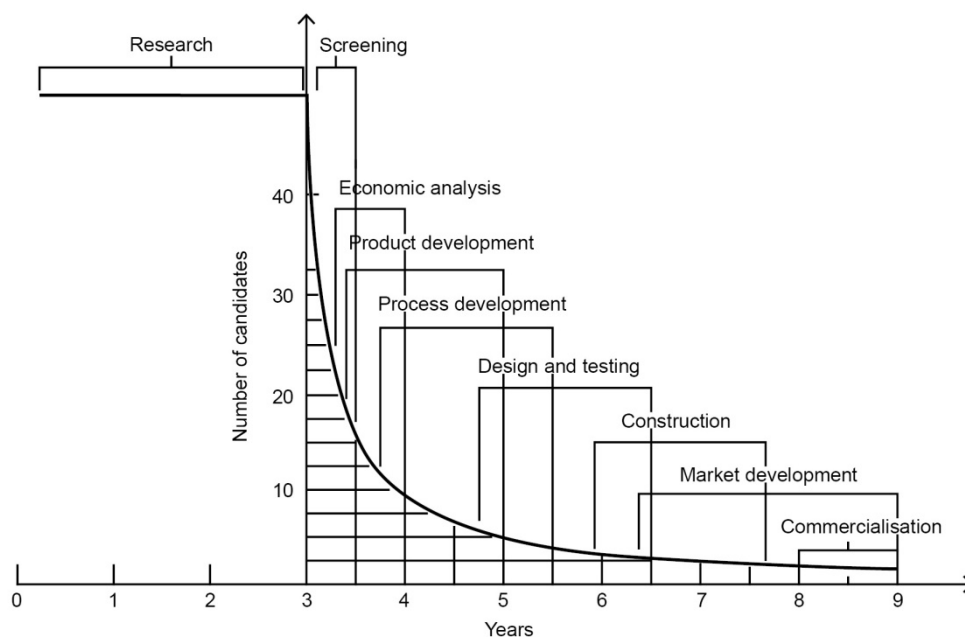


Figure II : New Idea Mortality Curve From Research To Commercialisation For Chemical-Product Ideas

Source : Adapted from Meredith & Gibbs. The Management of Operations, John Wiley, New York.

The curve also shows that converting product ideas into marketable products is a slow process. For chemical products, on an average it takes six years to commercialise a product after the initial research has been completed, as is shown by Figure II. At the end of it all, a product commercially launched may not turn out to be successful and the mortality may extend to the product as well.

The actual figures in Figure II are only indicative and within an industry firms differ in the speed at which they can convert a product idea into a commercial product. Some organisations are more innovative than others and they are always ahead with more new product ideas. Similarly, some organisations are more risk-taking than others and attach a high priority to being a pioneer with new products than others who are relatively risk-averse. They would like to do a more thorough job of screening, economic analysis, product development, design and testing and would perhaps also wait-it-out to see how some others have fared with similar products.

Cost of New Product Ideas

The new idea mortality curve also points to another fact by implication. The cost of pursuing different new product ideas till their abandonment is also to be borne by the few successful products. This significantly increases the cost of new product development and justifies the rationale of collaborative research. The research and development for a product is carried out at one place and later on the knowledge gained is made available to the collaborating organisations, which are then free to make independent product

developments of their own. A similar concept holds for our industrial research institutions in the government sector. For example, in the early stages of development of the television industry in India, Central Electronic Engineering Research Institute, Pilani (CEERI) around 1980s developed an indigenous design of a black and white television set and made it available to television manufacturing organisations for a fee.

2.3 SELECTION OF THE PRODUCTS

At the research stage, the priority should be generation of new ideas. In fact, it is better not to start the screening process till a reasonable opportunity has been provided to generate all new ideas. This is because different thought processes are required for generation of new ideas and for a rational analysis of the same. Consideration of one new idea may generate a better idea whereas an evaluative analysis introduced early in the process may hamper the creative process of idea generation. Some techniques of idea generation, for example, brainstorming, explicitly prohibit any analysis or criticism (based on analysis) of suggested ideas at the idea generation stage.

Once a number of potential new product or service ideas have been generated, the process of screening them to evaluate and select the 'best' idea is set in motion. This can perhaps be discussed in two phases—a qualitative phase where the new product idea is studied in terms of its match with the corporate objectives and the corporate strategies of the organisation. The second phase is more quantitative in the sense that potential costs and revenues (or benefits) generated by new product are quantified and an economic analysis is performed to establish the economy viability of the new product or service idea.

Screening

The new product or service idea is assessed to establish its market viability as well as to find out if it is in the larger corporate interest of the organisation to add this new product or service to the current outputs of the organisation.

A product or service has to have sufficient demand or else it may not make much sense to produce it at all. Of course, what is considered sufficient by one organisation may be considered to be grossly insufficient by another. Also the demand for a product or service is dynamic and although the current demand for a product or service may be assessed to be low, an organisation may still decide to retain the new output idea for further analysis if it assesses that the demand will grow in future. For example, vacuum cleaners are still in the introduction phase of their product life-cycle in India and an organisation may select this as its product if it assesses that sales will grow in the near future.

Each organisation has some corporate strengths and weaknesses. New product or service ideas should capitalize on the strengths and should attempt

to reduce the weaknesses to the extent possible. On the other hand, if one of the determinants of success for a new product or service idea is already perceived to be a corporate weakness, such a product or service does not have a good 'fit' with the strength and weakness profile of the organisation. For example, if strong design capability is identified as a corporate strength of an organisation then adding heat exchangers to its list of products—which have to be custom designed and built—is trying to exploit a corporate strength. On the other hand, another organisation which has identified design capability as one of its weaknesses would perhaps select centrifuges which are standard products and offered off-the-shelf.

It is important to realise the strengths and weaknesses are relative and also perceptive. The same feature can be perceived to be strength by one organisation and as weakness by another. For example, low investment in capital assets can be considered to be a strength since this gives the organisation greater flexibility in product selection and adjusting to changes in demand whereas the same can be perceived to be a weakness when capacity cannot be hired from outside or the quality of jobs got done from outside is unsatisfactory. What is important is to ensure that there is a close match between the strengths and weaknesses of the organisation and the requirements for the product or service to succeed.

In product selection, many organisations try to get synergistic results by exploiting one or more of the following four factors:

- i) Familiarity with similar products or services
- ii) Familiarity with the same or similar production or transformation process to produce the product
- iii) Familiarity with the same or similar markets or market segments
- iv) Familiarity with the same or similar distribution channels

Thus, it is perhaps natural for a firm manufacturing ceiling fans to include heat convectors in its product list, wherein it can benefit from its familiarity with similar production process, similar market segments and even the same distribution channel. On top of it, it can also reduce its weakness of having a highly seasonal capacity utilisation.

The above discussion also highlights the fact that any new idea for product or service has also to be seen in relation to the effect on the existing products or services. A new product may find a market for itself by cannibalizing one of the existing products. A new brand of a biscuit may create its market by a corresponding reduction in demand of another brand from the same firm unless the two are carefully targeted at different segments.

We have referred to the strengths and weaknesses of an organisation as relative, but relative to what? Of course relative to the competition. If there is no competition, which is very unlikely, there is no need to match the product requirements with the relative strengths of an organisation. For totally new

products or services, even if there is no competition presently, very soon competition will perhaps develop and it is the desire to remain ahead of the competition that provides the motivation for continuous inflow of new product ideas. Whatever be the relative strengths and weaknesses of any organisation, it is very unlikely that an organisation can be successful if its strengths are only in marketing, finance and other non-operational areas. In fact for long term success, it is almost imperative that sound operations management is one of the strengths of the organisation.

Sometimes a new product or service idea having very poor match with the existing strengths and weaknesses of the organisation is consciously adopted. This can happen if the organisation feels that the existing products or services have reached the decline phase of their product life-cycles either on their own or due to some changes in the environment e.g. government policy, introduction of better and cheaper substitutes and changes in prices of some inputs etc. For example, when ITC Ltd. Decided to diversify into hotels, this new service idea did not exploit any of the four familiarity factors (explained earlier) which could have given some synergistic results.

Economic Analysis

An economic viability of a new product or service idea ties up most of the concepts that we have talked so far in quantitative terms to the extent possible. What this means is that the economic value of the returns must exceed the economic value of the costs incurred to produce the output. For commercial organisations, the measurement of the returns and costs is relatively straightforward and economic analysis in a way becomes synonymous with profitability analysis. The cash flows generated as well as consumed, if the new product or service idea is implemented, have to be estimated for the life of the project. However, since there is a time value of money these cash flows cannot be directly added or subtracted. So, the cash flows are discounted to take care of the time value of money and the net present value of all cash flows is obtained—or else the cash flows are used to find an internal rate of return. The details of how to discount cash flows are discussed in the further course.

Non-Profit Organisations

For non-profit organisations, there may not be a cash inflow at all, or else the cash inflows may occur at externally fixed prices. For such organisations economic analysis generally means a cost benefit analysis, which is similar to the cash flow analysis mentioned earlier but now the net present value of all benefits less that of all costs is used as an indicator of economic viability. The benefits imply an addition of real resources to the society as a whole whereas the costs imply using up real resources as a result of implementation of the new product or service idea. These items of cost and benefit are valued so that they reflect the social willingness to pay for the same. Wherever free market conditions exist, the market prices can be used to value the costs and

benefits. On the other hand, economic prices are first estimated and then used to value those costs and benefits for which free market conditions do not exist,

Economic analysis is, therefore, much more difficult for non-profit organisations than for organisations having a profit motive.

2.4 PRODUCT DEVELOPMENT

Product development concerns itself with modifications or extensions provided to ideas so as to improve the functioning, the cost, the value-for-money of the product. Development effort improves the performance of the product, adds options and additional features and even adds variants of the basic product. On the whole, development effort is innovative vis-à-vis research which is more inventive—the thrust being on developing new product ideas, technologies and processes.

Product Development is the work contributing towards improvement in the existing knowledge by why of improved ideas, systems and techniques etc.

Development Efforts

Figure III charts the development effort over time for a typical product. The figure also shows the effort made for research to show the relative magnitude of effort as well as the timing of the two. Development starts after research has established an idea which has been examined, evaluated and even refined. The development effort rises initially as the performance of the product or service is improved and as the product itself graduates to the growth phase of its product life-cycle. The development effort still continues to rise but now the result is mainly providing options. As the product reaches its maturity, the development effort has peaked and thereafter gradually starts reducing. In this phase, product variants are developed and offered so as to lengthen the life cycle. This is followed by extensions of the product and Figure III highlights the fact that product development is an ongoing process which starts as the product is launched in the market and continues till it is withdrawn from the market.

What is more important — research or development? Development can start only when research has produced a product or service idea which is technically feasible and economically viable. However, greater effort is expanded on development as compared to research in most parts of the world today than it was, say 30 years ago. This is partly because the new products e.g. colour television, are more complex and require longer to debug and to improve their performance. This could also be true because research has become very expensive and organisations are under pressure to commercialise research as early as possible, even before the product or service ideas have been refined and debugged. But one possible consequence

of this shift away from research is that organisations make themselves vulnerable to technological breakthroughs which can give rise to a whole new generation of the product or service itself. The tradeoff between research and development is an important strategic decision for most organisations.

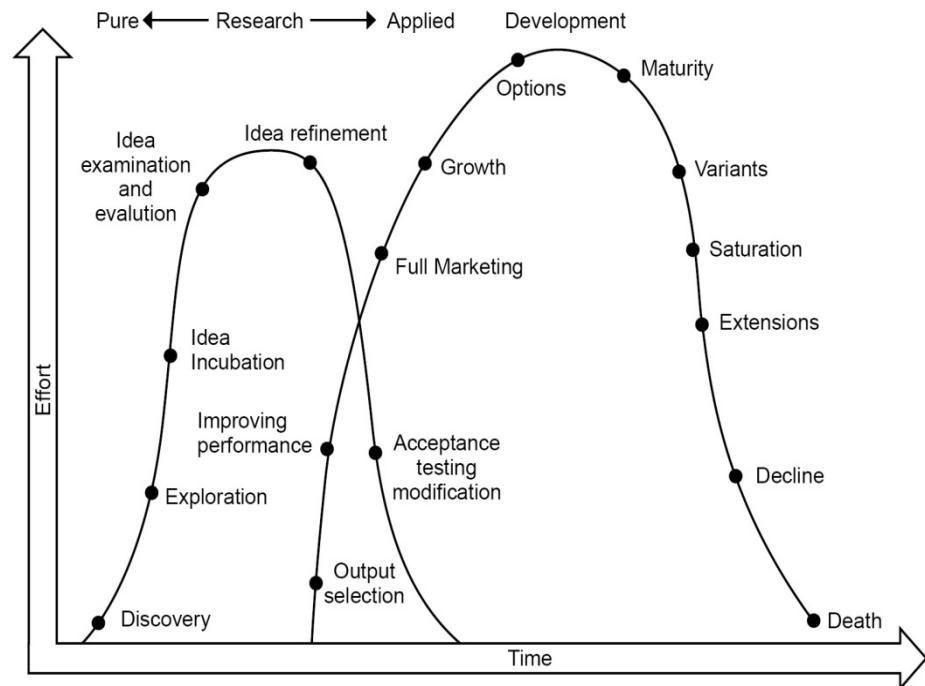


Figure III: The Development Effort Through The Product Life-Cycle of A Product

Source: Meredith & Gibbs, The Management of Operations, John Wiley, New York.

2.5 PRODUCT DESIGN

Product Design is defined as visible and tangible expression of an idea.

At the design stage, detailed specifications are provided so that manufacturer can produce what has been designed. This means not only providing dimensional specifications but even specifications regarding capacity, horse power, speed and colour etc. are laid down and the task of manufacturing is to convert the design into physical entities.

Product Variety

There are two distinctly different priorities that can affect the design of a product or a service. The higher the standardisation, the greater will be the ease in producing. On the other hand, customers have different needs and by adding variety, one can satisfy more customers. Standardisation attempts reduction in variety and better use of productive facilities, thereby achieving lower unit costs. If the demand for the product or service is strong when the price is low, organisations will try to minimize unit costs through standardisation and most of the competitions will be based on prices. There are other cost-related advantages due to standardisation. It simplifies operational procedures and thus reduces the need for many controls. The

organisation can buy raw materials and components in bulk and thus get quantity discounts. It enables steady flow of materials through work centres and thus reduces the number of production set-ups related to change in flow. It reduces the total inventory of raw materials, work-in-process and finished goods. Finally, since the effective volumes become larger as the variety is reduced, high-volume production methods become viable thus giving economies of scale in production itself.

Standardisation is a very useful concept but production needs have been given the highest priority in this scheme of things. This may be a very good approach to product design as long as cost is the primary basis of competition. Otherwise, one can design a product to suit the diverse needs and tastes of the customer. All watches are meant to display the right time but still a company like TITAN has hundreds of models of watches with different movements, dial shapes, sizes and other features. By adding variety, an organisation attempts to satisfy the varied needs and tastes of its customers and competes on non-price considerations as well.

One method used to obtain variety or perceived variety and yet hold down cost is through modularisation. A product is designed using modules or sub-assemblies that are interchangeable and each different combination of modules gives a new variety of the product. For example, two different movements, three dial shapes, two dial sizes for each shape and three different colours will give $2 \times 3 \times 2 \times 3$ i.e. 36 varieties of watches, yet making large quantities of standard modules.

Design simplification attempts to simplify the design so that the product or its parts become simpler to produce. This might mean combining two or more parts into one so that some assembly operations are eliminated. In some other situation, this might involve replacing screw fastened parts by parts which can be snapped tight in place without any fasteners. Design simplification gives pay-offs in terms of lower production costs and in some cases by lower material costs as well.

Structuring of Options

Options provide variety to a product increasing its attractiveness to a spectrum of users while retaining operations as simple as possible. We can see optioned products everywhere — from computers and office furniture to automobiles and machine tools. Even services have options built-in, for example in vehicle insurance.

Structuring the options is a major part of making a product line competitive when not competing on costs alone. However, options bring in their own complications as well. For example, pricing becomes much more complicated since each option may not have the same margin. A lot of sales effort is required explaining options or determining what the customer wants and it complicates the customer's choice. Options also give the customers an opportunity to change their mind and this creates additional difficulties where

the product is made-to-order. All options are not used to the same extent and low-usage option parts become hard to plan and control when mixed with a high-usage option part.

CAD/CAM

A part can be computer designed (computer-aided design) and its fabrication instructions can be generated by computer-aided manufacturing (CAD/CAM). This has the advantage that the manufacturing equipment is not tied up for long periods during setting up time. Practically all the preparation time is in programming where detailed instructions regarding the physical task to be performed and the sequence in which these have to be performed are written into a programme which can be read and executed by a computer having the machine tool or any other manufacturing equipment under its control. This then allows for very small batch sizes without losing on economy. Finally, because information regarding the design and the manufacture of the product and component is available on computer files, it is possible to use the data together with other information on materials, tools, etc. for production planning and control purposes thus achieving computer-integrated manufacturing (CIM).

Design Characteristics and Tradeoffs

By now it should be quite clear that there are many product features which can be affected by product design. In fact, Operations Management normally has a major role to play while final product characteristics are set. The **key elements** to be considered in product design are:

- a) **Function:** the new design must properly meet the recipient's need and perform the function for which it is designed.
- b) **Cost:** the total cost incurred in producing the new design should not be excessive, else that will affect its demand.
- c) **Quality:** the quality of the new design should be as high as possible, within the constraints of the cost. Quality can cost money and superior quality will increase the cost and reduce demand, whereas inadequate quality will affect the performance and lead to complaints and fall in demand.
- d) **Reliability:** the new design should function normally without failures for the expected duration. This is more important for complex designs involving many elements and the design must provide for redundancies and high reliability of elements so that high system reliability can be obtained.

The other elements which are also important in a product design, perhaps to a lesser degree are:

- e) **Appearance:** if the new design can be made more attractive, without sacrificing on the other attributes, that is only likely to improve the

demand. The relative importance of appearance varies from product to product and in many industrial equipment, it may have a relatively small effect.

- f) **Environmental Impact:** the new design should not degrade the environment.
- g) **Product Safety:** the new design should not pose a hazard to the recipient.
- h) **Productivity:** the new design should be producible with ease and speed.
- i) **Maintainability:** this is particularly applicable to consumer durables and industrial equipment. If a failure occurs in the equipment, it should be easily repairable with a minimum of down time.
- j) **Timing:** this is particularly relevant for design of services. The service should be available when desired by the recipient
- k) **Accessibility:** this element is also applicable to services. The recipient should be able to obtain the service without difficulty. The last two factors are important for design of services since services cannot be inventoried.

In both product and service design, many alternatives usually exist that will meet the basic function of the output. The design task is to recognise the major characteristics of the demand and to carry out a detailed analysis of the tradeoffs available among the various design alternatives, so as to meet the needs of the recipients as closely as possible. Sometimes, when the needs of the recipients are diverse, design will produce different models or versions of the same basic product to satisfy the needs of different segments of the market. This can be seen from the various models of television produced by almost every television manufacturer or the economy and the executive classes of air travel offered by Airlines companies.

The Impact of Product Innovation on Process Innovation

The design of a product or service has very close linkages with the design of the process required to produce it. In some cases, the product design itself becomes feasible only because of technological innovations. Throughout the product life-cycle, the process of product development goes on and we have looked into this aspect in section 2.4. It has been found that similar innovations take place in process design as well and this is shown in Figure IV below.

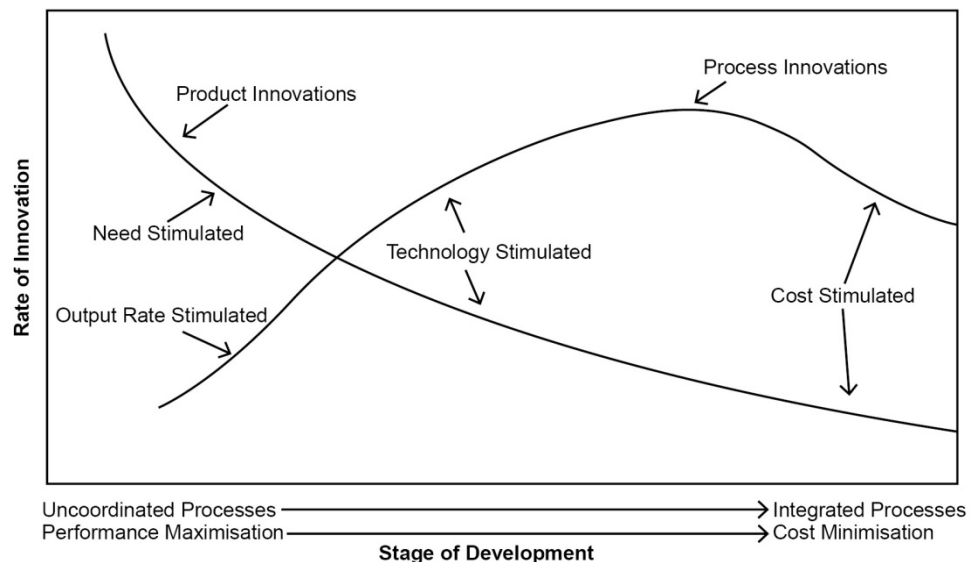


Figure IV: Product And Process Innovations in the Life-Cycle of a Typical Product

Source : Buffa E S, Modern Production/Operations Management, Willey Eastern, New Delhi.

Figure IV: shows that in the first stage, product innovations are primarily need-stimulated and the emphasis is on maximizations of product performance.

The process is typically uncoordinated in this stage and process innovations are primarily output-rate stimulated. Product innovations are gradually decreasing while process innovations pick up at this stage.

In stage two, both product and process innovations are technology-stimulated. The productive system design emphasises cost minimization as competition in the market begins to emphasise price. Process innovations start dominating over product innovations as they yield greater reduction in cost.

The product or service has reached maturity and saturation by the third stage and innovations are stimulated primarily by cost considerations. The productive processes become highly integrated and product-focused operations try to achieve economies of scale by having integrated plant of large capacities.

2.6 INTRODUCTION TO PROCESS SELECTION

The transformation process that converts inputs into outputs with added value is the core element in the operations function. The selection of the process is therefore a strategic decision for most organisations. The process selected will, to a very large extent, determine both the quality and quantity of men and women to be employed as well as the amount of capital required for the production of goods and services. Infact, many organisations are slowly coming round to the view that operations has been the missing link in the

traditional approach of formulating a corporate strategy wherein the production or operations function is expected to play a supportive role to marketing.

Undoubtedly, marketing has to establish what is to be produced to satisfy the needs of the customers. However, the traditional approach is partly based on the view that $\text{PRICE} = \text{COST} + \text{PROFIT}$. Looked at this way, the price of a product or service is obtained by adding a profit element to the cost incurred in producing the same. This view of looking at profit and price may not have any serious problem if the environment is less competitive. But as markets become more competitive, the customers have more choice in terms of product attributes like design, functions, ease of use, performance, quality and cost.

The transformation process, therefore, has to be so selected that it can provide the desired product attributes and at the same time remains cost-effective. This can be best achieved by taking a strategic view of the production/operations function and by integrating the operations function including process selection while formulating the corporate strategy of the firm.

In this unit, we shall discuss the major factors involved in the selection of the transformation process, the various alternative process forms available and the process involved in selecting an appropriate transformation process.

Process Selection as an Adaptation

The major considerations in any process selection e.g. capacity, flexibility, lead time, efficiency in using resources are so interdependent that changing the process to alter one will almost invariably alter the others as well. There are numerous tradeoffs available while selecting a process—between different materials, between requirements of labour and capital, between volume and variety, between cost of production and flexibility and so on. It is important to know the consequences of every such tradeoff.

The transformation process selection is a complex decision because of the existence of so many tradeoffs, many of which are also interdependent. Generally speaking, there is no concept like the best process for a particular conversion. Rather, many times it is an attempt to find a process which produces acceptable levels of attainment on many objectives some of which are incongruent. For example, we want a process which is flexible as well as instrumental in producing outputs with least cost.

Obviously, we cannot have both and so our attempt will be to select a process which has acceptable levels of flexibility and cost. One can give similar examples from the other tradeoffs mentioned earlier. Such a situation only highlights the need to integrate these decisions while formulating the corporate strategy of the firm.

By now it should be clear that any change in the host of factors mentioned above will have a profound effect on the process selected. For example, with the passage of time, if the volume or the variety of the products/services produced undergoes a change, a different process form might become more appropriate. Therefore, the process selection continues to remain an adaptive process.

Process Selection and the Environment

As a strategic decision, the process selection decision is influenced by the environment to a very great extent. With newer materials becoming available, as such a different transformation process might become more appropriate. This phenomenon can be seen very clearly wherever plastics are being used as newer substitutes of some natural material. Metal containers giving way to plastic containers mean a totally different transformation process for the company manufacturing containers. New synthetic packaging materials have caused significant changes in the process involving packaging of consumer products.

Similarly, development of new technology may render a process obsolete as the new technology is more economical, uses cheaper material or produces goods with a higher quality level. Bolts can be made by machining hexagonal rods. However, with the development of cold forging, the material wastage involved in metal cutting can be totally eliminated giving rise to a process which is not only more economical but faster as well. Not only the manufacturing technology, but the technology involved in organising the operations function also has an effect on the process selected. This can be seen when concepts like Group Technology or Autonomous Working are used and we shall discuss these concepts later in this unit. The competitors might also affect the process selected for a transformation. For example, when the competitors can deliver the product or service much faster than us, this may lead to a review of the form of process selected for our operations function. Similarly, when we want to compete on non-price factors like quality, custom-made product designs, shorter lead times or easier availability, the transformation process has to be geared to the combination of such factors that we consider to be important.

2.7 FORMS OF TRANSFORMATION PROCESS

Process selection is actually a generic decision and in practice this refers to the selection of sub-processes and sub-sub-processes depending on the type of output that is produced. If the output is a product then, following the design of the product, this can be broken down into sub-assemblies and sub-sub-assemblies till we reach an elemental level of components which cannot be broken down further. Now, for each of such components we have to decide whether to produce it ourselves or to buy from outside. If it has to be produced by us, then the process selection decisions concern the technology

to be used, the sequence of operations to be performed, including in process storage and transportation from one work centre to another, equipment required for the transformation, staffing, the detailed work place layout, design of special tools, jigs and fixtures and so on, If the product requires an assembling of components and sub-assemblies, then the assembly process has also to be selected and designed appropriately. In fact, there may be no best way to produce a product or service; rather it may always be possible to improve both the output and the process selected to produce it.

Establishing the Volume and the Variety

One of the major considerations for process selection is knowing where we want to peg our organisation on the volume/variety continuum. The volume/variety continuum can be conceived of as an imaginary straight line, one end of which refers to very high product variety implying each product to be different from each other, consequently having very low volume viz., only one of each product. As we shall see later in this unit, such high variety requires the use of highly skilled labour, general purpose machines and in general, detailed and complex operations, planning and control systems.

The other end of the continuum refers to very low product variety implying a single standard product that is produced in very high volumes. Such a combination enables us to use highly automated, mass production processes using special purpose machines and simple production planning and control systems.

Produce-to-stock or Produce-to-order

A related consideration for process selection is whether the product is to be produced and stocked in our warehouses to be sold as and when the demand occurs, or is to be produced only on receipt of an order from the customer. It is a related consideration because, usually standard products with less variety are produced in batches and as sales proceed, we draw the products from the inventory. When the inventory level touches a predetermined minimum level, a fresh batch of the product is produced and such a cycle goes on. In this system, goods are produced in anticipation of sales orders and the customer gets immediate delivery and does not have to wait. However, such a system can work only with inventoriable products and the shorter the shelf life of a product, the higher the risks undertaken by the producer. For example, newspapers have a very short shelf life and so the risks of overproducing as well as under producing are high.

When we produce-to-order, the production process starts after receiving the sales order in quantities dictated by each sales order. All custom-made products are produced-to-order since the exact specifications are known only after receipt of the order. In such a system the customer has to wait while his products are being produced and so the longer the lead time for production, the longer the waiting period.

Services, by their very nature, cannot be inventoried and so services have to be produced to order. The transformation process in such a system has to be so selected and designed that the waiting time for a customer is not excessive.

Finally, we can have a combination of both these systems as well. For example, where a large number of options are provided on the product, the components and sub-assemblies might be produced to stock whereas the final assembly is carried out on order. In restaurants, food is semi-cooked in batches i.e. produced to stock and the final dish is prepared on receipt of a customer order i.e. produced-to-order.

Effect of Output Characteristics

In the previous sections we have said that the form of the transformation process depends to a large extent on output characteristics like volume/variety and whether produced-to-stock or produced-to-order. Figure I illustrates these comments by showing the relationship in a diagrammatic form.

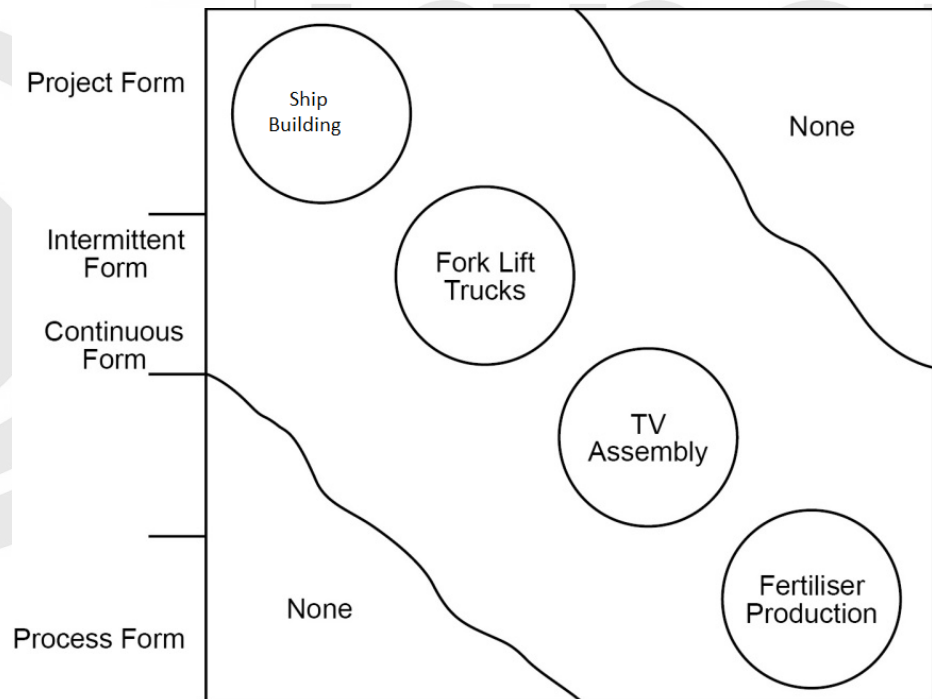


Figure V : Effect of Output Characteristics on The Form of Transformation Process

Source : Adapted From Hayes, R.H. et al., “Link Manufacturing Process and Product Life Cycles.” Harvard Business Review.

The horizontal axis which shows the output characteristics is represented in terms of the batch size. On one extreme we have products produced in batches of size one, i.e. each product is different from the other. On the other extreme we have products produced in infinitely large batch sizes, These are products with no variety and have the characteristics of a commodity like fertilizer, sugar and cement etc.

The form of transformation process is similarly represented on the vertical axis. The top end represents the project form where each project is followed by another project-no two projects are exactly alike and detailed planning, scheduling and monitoring has to be performed to keep the project costs and durations under control. As we go down the vertical axis the flow of materials becomes more smooth and uniform. These can be categorised as batch production or interrupted form, mass production or continuous form, and finally, as the name implies the processing form wherein there is no interruption in the flow of materials at all, as in a petroleum refinery or a fertiliser plant. In the subsequent sections we are going to discuss each of these process forms in somewhat more details.

However, we would like to point out a couple of things in Figure V before we proceed further. First, as is shown in Figure V we would not find any process corresponding to the lower left hand region or the top right hand region of the Figure. That is to say, when the batch size is very small it is not at all advisable to use the continuous or the processing form of transformation. Similarly, when the batch size is really large, it is again inadvisable to use the project or the interrupted form.

The second point that emerges from Figure V is that for any batch size, there is usually a choice available in choosing the processing form. Thus, even in the same industry one may find different competitors using different processing forms and thus trying to create a special niche for themselves. For example, one manufacturer of ceiling fans might choose the interrupted form whereas another might decide to adopt the continuous form of production and both might coexist in the same competitive market.

It is also not difficult to see that Figure V also holds good for services (except that there is no processing form for service). The service provided by a lawyer on a law-suit is almost always of a project form. Services provided by a government agency is usually of the interrupted form whereas for some high volume services the continuous form is employed. In fact, in recent years, as the service sector is growing faster than other sectors, more and more services are gradually being pushed down the vertical axis of Figure V. Fast food service is a typical example of this phenomenon.

2.8 THE PROJECT FORM

Project operations are characterised by complex sets of time-bound activities that must be performed in a particular order. Distinctly different from all other forms of transformation process such that each project has a definite beginning and a definite completion, the project form of transformation is very useful when complex tasks involving many different functional specialisations have to be performed against strict deadlines.

If the output of the transformation process is a product, such products are generally characterised by immobility during the transformation, Such

operations are referred to as Fixed Position assembly and can be seen in the production of ships, aircrafts, and construction of buildings, roads, etc. As projects have limited lives, a project team is usually set up to manage a project. Resources such as men, materials and equipment are brought together for the duration of the project. Some materials are consumed in the transformation process, while others like equipment and personnel are redeployed for other uses at the end of the project.

We give below a small list of projects to clarify our understanding of a project:

- setting up a new thermal power plant
- building a hospital
- modernising a textile mill
- constructing roads, bridges, buildings
- organising an annual sales conference
- launching a new product
- punching and delivering a programme like Diploma in Management
- computerising the purchase and the inventory control system
- conducting a two-week training programme.

The number and importance of project operations is growing at a very fast rate in most societies, including ours. We shall now discuss some of the possible reasons for this growth in project operations. The benefits from various development programmes are delivered through projects. With the spread of education and rise in income levels, people themselves organise projects in the areas of community development, travel and tourism, social functions etc. Each knowledge area is getting more and more specialised and on many jobs we now need inputs from different specialisation areas. The project form is very suitable to handle inter-disciplinary specialist groups.

The fast-pace of technological developments is forcing many companies to adapt to the new technologies. Such developments are taking place not only in the manufacturing technologies but also in packaging technology, material handling technology, computer technology and so on. Implementing a change is usually carried out through a project operation. Increased competition, similarly, is forcing companies to launch projects on cost reduction, higher productivity, better methods and so on.

Whenever a transformation process is to be carried out under severe time and cost constraints, i.e. whenever the penalty associated with time and cost overruns is severe, the project form of transformation is the most suitable. With ever-higher prices of equipment and labour, the cost of delay in many activities is becoming intolerably high and that is another reason for the speedy growth in project operations.

Choosing the Project Form

There are many situations in which the project form of the transformation process is the most appropriate. Obviously, if the tasks involved are for a limited duration, there is perhaps no alternative to using the project form of operations to carry out the tasks within the time frame prescribed.

The project form also offers extremely short reaction times to changes-both internal and external. Thus, if the outputs belong to high technology areas where the product design and/or the process technology is changing at a very fast pace and the operations have always to be kept abreast of the latest developments, again the project form may be found useful. For example, the project form of operations is used very often when we are selling chemical plants.

When a transformation process requires inputs from many specialisation areas, the project form of organisation is known to perform well. This is because the project form draws upon a mixed complement of personnel from different functional specialisations (e.g. mechanical engineers, civil engineers, chemical engineers, marketing and financial specialists etc.). However, the same feature of mixed complement of personnel does not allow the project form to advance high technology areas. Another process form where operations are organised by functional specialisations may be more appropriate if advances in high technology areas is one of the desired objectives. In the latter form, a group of specialists help in developing a process related to their field of specialisation. Such a group usually has access to specialised manpower as well as equipment which also contributes towards advancing technology. In the project form, generalised resources (staff and equipment) which are usually used as specialised resources will have a poor utilisation.

When the tasks involved are of very large scale involving many inter-dependent activities, the project form of operations is typically chosen. This is because the project form is better suited for detailed planning, monitoring and control of a large number of inter-related activities many of which are performed by different agencies.

Characteristics of Project Processes

Project operations are different from other forms of transformation process in the way resources are organised and deployed as also in the planning and control of various activities that constitute the project. In the following sub-sections we discuss some of these characteristics of project operations.

Short Life-cycle

Projects are designed to have a definite beginning and a definite end. Project processes are therefore different from all other forms of transformation processes in that they have a specific completion. At the end of one project, resources from this project could be redeployed elsewhere in other project,

processes or other operations. In fact, even during the life of a project, resource requirements are not uniform. Thus in the initial phase, resource requirements including manpower, are at a low level, But there is a fast build-up during which more and more resources are absorbed in the project. This build-up, however, gradually levels off and then there is a cutting back as the project nears its completion. However, the resource requirements in terms of a particular skill (e.g. design engineer, high pressure welder etc.) or a particular equipment (e.g. concrete mixer, pile driver etc.) may vary more unevenly and so resource levelling remains one the major difficulties in project planning and scheduling.

Consequent Personnel Problems

This phenomenon of a fast build-up, a levelling off and final cut back in resource requirements can give rise to two related personnel problems.

When there is a fast build-up, staff is generally borrowed from other departments and also some are hired for a short duration. Thus, they may have limited loyalty and short-lived interest in the project. This is further compounded by the fact that the staging area or the site for many projects could be in a different and relatively undeveloped geographical region and that causes some dislocations in the normal life of the persons involved. Finally, the persons may have limited experience with the special tasks involved in the project.

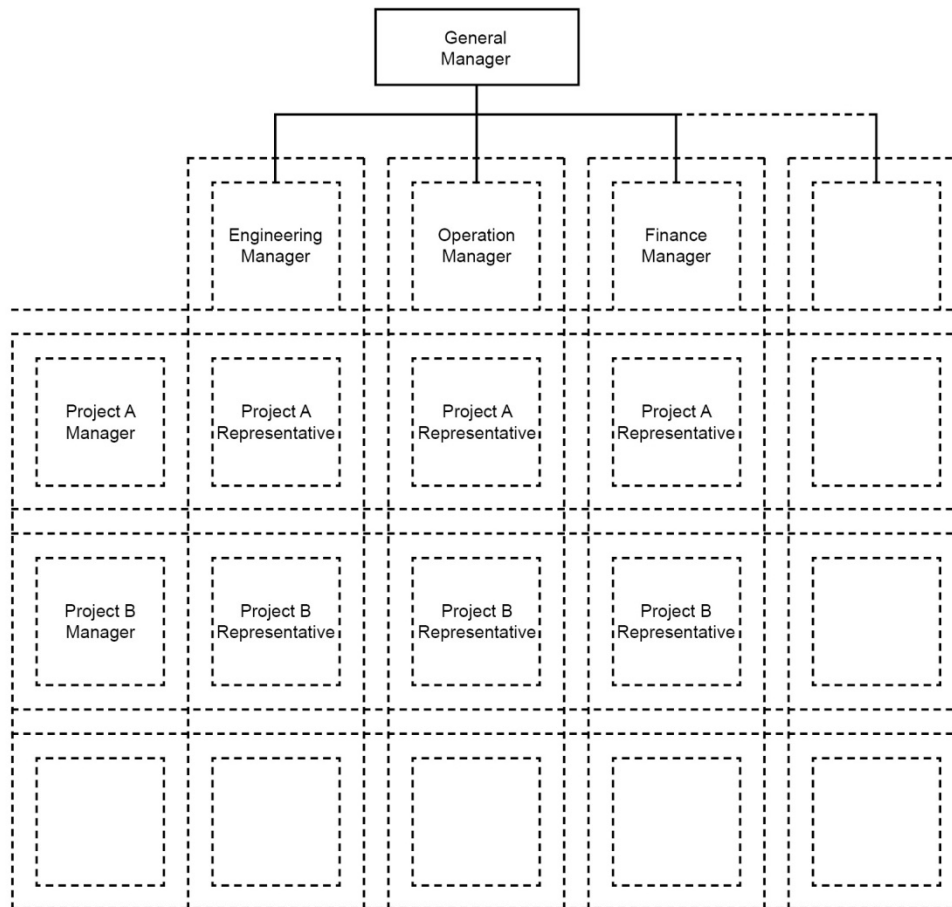
As each project has a limited duration and as the end of the project draws near, the staff may start spending more time getting prepared for the next job. This is especially true if they are hired for the project and have to look for alternate jobs once the project is over. In the process, the project may get dragged beyond its scheduled date of completion.

Matrix Organisation

When multiple project operations are under way, a matrix organisation structure is generally used. In a matrix organisation, project representatives for each project are designated by different functional areas. As shown in Figure VI there are project representative from Engineering, Operations, Finance and so on for Project A. There are similar representatives for Project B and other projects. Thus, each functional manager holds the resources and each project manager coordinates the use of designated resources through the project representative concerned. This form of organisation allows coordination across functional departments for better use of resources. However, a major disadvantage of this form of organisation is that an employee has two supervisors--one in the project and another in his "home" or functional department. The need for coordination between functional and project managers is essential so that there are no conflicts in regard to questions such as: Who will evaluate and reward employees? Who is ultimately responsible for the discipline of employees? In the absence of such

coordination the project representative may find himself or herself in the unenviable position of having to satisfy two bosses with different priorities.

Figure VI: Matrix organisation structure for project management



Importance of Scheduling and Control

A project generally involves many tasks-each having its own specialisation and perhaps to be executed by a different agency. However, they have a strict precedence requirement-like one task cannot even begin until two other predecessor tasks have been completed. The cost of delay in completion of the project is also usually very high, many times with explicit penalties being mentioned as well. Because of all these reasons the scheduling and control of various activities in a project assumes great importance. Some network planning techniques like CPM and PERT have been specially designed to resolve these issues.

2.9 INTERMITTENT FLOW PROCESSES

When the output variety is large, each output takes a different route through the organisation, uses different inputs, requires different operations and takes a different amount of time and also sequence, the intermittent form of processing is often used. In this system, each output, or small group of similar outputs (referred to as a batch or a lot), follows a different processing route through the facility, from one location to another. The facilities are

organised around similar operations functions. For example, in an engineering organisation there is a foundry, a machine shop, a press shop, a tool room, a paint shop and so on. In a hospital, there is a blood bank, an X-Ray department, a pathological laboratory and so on. The flow through these departments depends on the exact needs of a patient. The intermittent process is especially suited for service organisations because each service is often customised and so each one requires a different set of operations in a different sequence.

Characteristics of the Intermittent Form

Referring to Figure V the intermittent process form is generally suitable when the variety is large and consequently the volumes are low. The transformation process should be able to take care of this large variety and also in a manner that the cost of the processing is not excessive.

Flexibility

When an organisation wants to produce a variety of outputs using common facilities, it wants to have flexibility in its operations. This is achieved by employing general purpose machines and equipment as well as having staff with a wide range of skills. The facilities are laid out in accordance with the general flow and for specific outputs, there may be a lot of movement as well as backtracking depending on the sequence of operations required. Not only the processing, even the inputs required for different outputs could be quite different.

Even if the final product does not have excessive variety, e.g. in manufacturing of typewriters, the intermittent form is still used for the manufacture of components: This is because a large number of components are assembled into a typewriter and the same facilities could be used in making many different components in batches. One batch of 1000 pinions could be produced this week and the next batch may have to be produced only after one month. By splitting into batches in this manner, a large number of different components can be produced on a common set of machines. All this is possible because the intermittent form of processing is flexible.

Around Standard Operations

The transformation processes are organised around standard operations in the intermittent form. In a bank, this would result in departments like cash, advances, deposits, savings bank accounts and so on. Any customer who wants to deposit or withdraw cash, has to go to the cash department for this purpose.

In such a scheme, each functional group is a specialised group and performs all tasks connected with that specialisation. That is why the workers need to have a width of skills so that they can perform a range of tasks-of course within the specialisation. A machine operator in a grinding shop will not be producing the same output everyday and thus besides skills in operating

different types of grinding machines needs the ability to read blueprints and perhaps also the ability to set up' grinding machines to perform different jobs.

The amount of specialisation achieved by organising around standard operations enables the organisation to solve complex and specialised problems. Thus, a difficult grinding job is more likely to be carried out by an organisation having a grinding shop than by another having project operations or even continuous flow processing where grinding operations are also being performed.

Material Handling and In-process Inventory

As the grouping of facilities is around standard operations, the partly processed output is to be transported from one standard operation to another. The amount of material handling for an output or a batch of output depends on the number of standard operations to be performed and also the distance between the locations where the operations are performed. For all the outputs of the organisation, therefore, the amount of material handling would depend on the output mix and the layout of different facilities. A great deal of effort is made to design the facilities layout so that the material handling is reduced for a targeted output mix.

Again, as the same facilities are being used for the processing of many outputs, the flow of materials through the facilities is not smooth, but interrupted. After one operation, the partly processed output or batch of outputs may have to wait if the facilities required for the next operation are busy on the processing of another output on batch. Such material is referred to as work-in-process and the consequent in-process inventory is typical in intermittent flow processing.

Difficulty in Management of Resources

Since each output or batch of outputs is different, the planning and control of the operations function is very difficult under intermittent flow processing. Elaborate planning and control procedures are used so that the movement of each output or batch of outputs can be tracked and all the inputs required for a particular output or batch be made available in time. The planning and control becomes more difficult in the absence of accurate time standards as the outputs may not be repetitive.

Advantages of the Intermittent Form

In transformation processes, there is always a trade-off between flexibility of operations and the efficiency of use of resources. Intermittent transformation processes are chosen whenever flexibility is considered more important than mere efficiency.

Variety at Low Cost

The intermittent form of processing is appropriate when we want to respond to demands of small volume and high variety. The primary advantage of this

form of processing is, therefore, the ability to produce a wide variety of outputs at a reasonable cost.

The choice of machines and equipment, the skill of the staff, the layout of the facilities and all related decisions emphasise the need to have flexible operations which are also not very costly. In intermittent flow processing, general purpose machines are generally used as these are cheaper than special purpose machines, since they are in greater demand and generally available from more suppliers. Also, they are easier and cheaper to maintain and dispose of thus reducing the cost of obsolescence. Because of the diversity in outputs, all the equipment do not have hundred per cent utilisation. The cost of unutilised equipment is low, as the equipment is simple general purpose and not very costly.

High Capacity Utilisation

As facilities are grouped around standard operations, all the outputs requiring a particular operation will have to be sent to the section carrying out that operation. Thus, there will be a high capacity utilisation for equipment grouped around that operation. The cost involved in providing special environmental conditions for some operations e.g. airconditioning, dehumidifying, dust proofing etc. is also minimised as all such equipment is physically close to each other when the organisation is laid out for intermittent form of processing.

Staff Advantages

Each worker performs a complete operation under intermittent processing—e.g. completing an analysis on a form, painting a component or product etc. This, complemented by the fact that the task itself is not repetitive, provides the workers pride of workmanship and increased responsibility. There is usually a high morale, in the group when all the group members are similarly skilled and work in the same location.

Disadvantages of the Intermittent Form

The intermittent form will not remain the best form of processing if the volumes for some outputs become high. The in-process inventories could become excessively high and the operations planning and control could get out of hand necessitating the use of expeditors.

More Costly for High Volumes

The initial cost for general purpose machines, which are mostly used in intermittent processing, is low. But they are usually slower than special purpose machines and also give lower quality of outputs. The skilled operators are paid more than the semi skilled or the unskilled. The end result being that although the fixed costs are lower for general purpose machines, the variable costs per unit of output are higher. For low output volumes, therefore, the general purpose equipment could be the cheapest as well.

However, as output volumes rise, the advantage in terms of a lower fixed cost is more than compensated by a higher component of variable cost and thus the special purpose machines may offer the least cost alternative.

Complex Operations Planning and Control

As mentioned earlier the planning and control of operations is very complex for the intermittent form. When the number of jobs on the shop floor rises to high levels, it becomes almost impossible to keep track of individual jobs. Over and above the paperwork involved, "expeditors" are employed to reorder priorities and track down specific jobs.

The requirement of each output being different, in the absence of such detailed planning and control there may be production bottlenecks on some facilities whereas resources may remain idle at some other facilities. It is easy to see that there may be a host of reasons causing such idling of resources – e.g., machine breakdown, raw material non-availability, delay in a previous operation, absent worker, non-availability of tools etc. etc. It is the job of operations planning and control to ensure that all the inputs required for a particular operation are made available when the operation is planned.

Large In-process Inventory

Intermittent processing would always have some in-process inventory. However, as the variety of outputs and the scale of operations increase, the in-process inventory becomes larger. On top of it, there will be a fast build-up of in-process inventory if there is any laxity in the operations planning and control function. This increases the space requirement of operations and also disturbs the appearance of the operations area at times making it even unsafe.

The material handling equipment used in intermittent operations is generally mobile and is more expensive than the fixed position handling equipment like chutes and conveyor belts. It also requires more space for movement thus adding to the space requirement.

New Technology for Intermittent Flow Operations

There have been quite a few developments towards increasing the efficiency of intermittent flow operations. Many of these developments are based on using the computer for many planning and control activities and some, like group technology are based on using continuous flow principles for outputs which have a large variety.

Computerised Production and Inventory Control Systems

Many different types of computer packages are available which can link the input and output requirements, check with the inventory at hand and automatically raise purchase orders and also prepare different types of statements for planning and control purposes. Given a schedule of output requirements, the computer can work out the requirement of raw material and

other bought out items and can plan the procurement and production of these so that there is no hold up of production due to non-availability of material.

Integrated Computer-Aided Manufacturing

These computer packages tie up the previous systems with mechanical systems that control machinery and material handling equipment. These packages do not carry out manufacturing of parts alone but also process planning, costing, tool design, production planning, material ordering etc. The rate of development in this area is extremely rapid and is also accelerating. Computers are used for both planning as well as execution of the plans.

Manufacturing Resource Planning (MRP II)

If the computerised production and inventory control systems could be linked with other planning and accounting systems of the organisation, it would result in comprehensive computer packages on manufacturing resource planning. Such a system would integrate marketing, finance, personnel, payroll and other systems and can prepare statements on funds requirement, promotional need, capacity planning and so on.

Group Technology

Group technology has developed over the years to become a complete philosophy rather than a single technique. The common thread running through all these techniques is the attempt to find groups which can be used in organising the transformation process. The purpose of grouping is to overcome some of the disadvantages of intermittent flow processing, and the grouping can be of component parts, machines, equipment and people.

In general, component parts are grouped into families so that the processing required for members of a family is similar. The machines and equipment are also grouped into cells so that the volumes through a cell are higher and the variety smaller. Therefore, the principles used in continuous flow processing can be used for each of these groups.

The benefits expected from group technology are really fourfold:

- i) reduced amounts of time and costs because the nature of operations and their sequence is similar for a family of component parts
- ii) reduced material handling as the machines and equipment in a cell are physically close to each other
- iii) shorter throughput times as the waiting period between operations is minimal
- iv) reduced in-process inventories, again because of minimal waiting between operations.

2.10 CONTINUOUS FLOW PROCESSES

As distinct from intermittent flow processes, all outputs are treated alike in this form of processing and the workflow is thus relatively continuous. The production process is therefore geared to produce one output, perhaps with some options added on. The variety is small and volumes are high thus making it worthwhile to focus the transformation process on the output. This would mean arranging the facilities in the sequence in which they are required for the output, using high speed special purpose machines, laying out the facilities to minimise the movement of materials and designing the production system so that there are no bottlenecks as well as no idle time for any of the resources.

Traditionally, services were considered to be too customised for this form of processing. However, we are now finding that by standardising the service and also by increasing the volume of output, it is possible to use continuous processes even for services. One can give the example of fast food joints or periodic servicing of automobiles towards these trends.

Characteristics of Continuous Processes

The continuous process form is characterised by relatively standardised outputs and consequently fixed inputs, fixed sequence of operations and also fixed processing time. As the variation from one output to another is very small, the transformation process is selected and designed to maximise the efficiency of the resources and in the process flexibility of operations is sacrificed.

a) High Volumes

If an organisation is planning to produce only a small variety of outputs and in high volumes, it will find the continuous processing form a very attractive proposition. Because of high volumes, one can choose those production facilities which are of special purpose and perhaps custom-built so that the initial costs are high, but they can produce the output at a low variable cost. The higher the volumes the further these tradeoffs shift towards higher fixed costs and lower variable costs. This is because the variable costs are low and the high fixed costs are spread over a high volume of output thus making the continuous processing form the least cost processing form for high volumes.

b) Easier Planning and Control

As all outputs follow the same path from one operation to the next, there is no need to keep track of each output for planning and control purposes. In other words, all operations being standardised with standard operation times and no waiting between operations, if the time when processing starts for an output is known, all subsequent operations including the final completion of the output can be predicted quite closely.

This implies that there is virtually no in-process inventory since there is no waiting between operations. Also, as the transformation process is designed specially for this output the amount of movement between operations is minimal. Further, as volumes are high, special purpose fixed position material handling equipment like chutes. Conveyors etc. which have low space requirements and operate at low variable costs can be used.

c) Linear Workflow

All the facilities are arranged in the sequence in which they are required for the production of outputs. The material therefore moves from one facility to another or from one location to another with no backtracking at all. That is why product organisations of this form are often called flow shops.

When the continuous form of processing is used for production of an output, we have, what is called a **product line**. In many product lines we can actually see the material moving on a conveyor and workers removing one unit from the conveyor for processing and putting it back on the conveyor at the end of the operation so that it goes to the next location for the next operation. It is, therefore, important that the work content at each of the locations be exactly equal so that no location has a bottleneck nor does a location have idle time. The rate of output will be governed by the slowest location (referred to as work station in the context of a production line). Sometimes, when there is a large variability in the operation times, a small in-process inventory is allowed to be built up to cushion out the effect of such variations.

When only assembly operations are performed on a line, such a line is called an assembly line. Assembly of many low variety production is carried out using assembly lines—for example automobiles, television sets and domestic electrical appliances etc.

Advantages of the Continuous Form

The continuous form of processing requires a great deal of effort while designing. But once implemented, it offers many simplicities in its operation.

a) Low Unit Cost

The main advantage offered by continuous process operations is the low per unit cost of production. As discussed earlier, this is achieved by selecting equipment which provides low variable costs of operation perhaps at high initial costs which are distributed over large production volumes. Further cost saving is possible due to bulk purchasing of materials, efficient facility utilisation, low in-process inventories and lower material handling costs.

b) Lower Operator Skills The machines used in continuous processes are generally special purpose and so their operation is simpler, with few

setups required. The operator skills required are therefore lower which improves the availability of workers with requisite skills and also gives rise to lower labour costs.

However, the special purpose machines are more complex in their design and functions and so are more difficult to maintain. Thus, higher maintenance skills are required and since the experience of working on any of these machines is limited, the time taken for diagnosis and repair is longer. Similarly, spare parts availability itself could be difficult for special purpose machines.

c) Simpler Managerial Control

As the workflow is streamlined in the continuous form, the planning and control of production is much simpler. With standardised operations and operation times, the predictability of operations is higher. This implies that the performance on meeting delivery dates is better.

In fact, while operating an interrupted processing system, if one of the outputs establishes a high growth in volume, it may be worthwhile exploring the possibility of setting up a production line for this output. Although the component parts are produced using interrupted processing, the final assembly is carried out on an assembly line for many products.

Disadvantages of the Continuous Form

Although the continuous form of processing offers a low cost alternative when volume of production is high and the variety low, there are some disadvantages in organising the production in this form.

a) Difficult to Adapt

As the whole production process is designed for a particular output, any change in the output characteristics is difficult to obtain. Because of this, important changes in product design are often not made, which can affect the competitive strength of the organisation. Each production or assembly line is designed for a particular rate of production. Sometimes, it is difficult even to change the rate of output. This causes serious difficulty when the demand for the output increases or decreases.

b) Possibilities of Stoppage of Line

If there is a break down at any work station or in the material handling equipment, the whole line may come to a standstill. In the absence of work-in-process, production at all workstations will suffer till the line can be started again.

c) Balancing the Line

The work content at each of the workstations should be exactly equal to avoid bottlenecks and idling of resources. However, if it is not possible to exactly equalise the work content, the output rate is governed by the

slowest work station which implies that workers at all other work stations are less busy. This remains a sore point among the workers.

d) Low Worker Morale

A worker's task is highly repetitive in the continuous form of processing and for high output rate production lines the task may also be very insignificant and unchallenging. This dehumanising aspect of the workers' role causes boredom, monotony and very soon starts affecting the morale of workers.

e) High Initial Cost

The special purpose machines and equipment used in continuous form of processing have very high initial cost. It is also costly to service and maintain. Also, such special purpose equipment is very susceptible to obsolescence and it is not easy to find a buyer for such equipment or to modify these for other uses.

New Technology for Continuous Flow Process

Recent developments in computer applications have had their effect on continuous flow operations as well. The attempt in all this is to increase the flexibility of production and assembly lines.

a) CNC/DNC

Machines and processes which have been automated using some form of electronic system are said to use numerical control or NC. In the early NC machines, instructions for machine control were coded on punched paper tapes to be read by tape readers. In CNC (Computer Numerical Control) machines, relatively simple programmes can be stored in the memory of the computer and so it is not necessary to read the control tape for every item manufactured. This is an advantage since the control tapes and the associated tape readers are among the most unreliable components of an NC machine.

In DNC (Direct Numerical Control) machines, programmes for a number of NC machines are stored in a single computer of larger capacity than the type used in CNC. Also, the integration of a number of machines and processes by one computer enables a set of machines to work as a manufacturing system, with parts scheduling and process monitoring. Automation by numerical control can be thought of, as soft automation as this allows fast changeovers from one component part to another.

b) Robotics

According to the Robot Institute of America, **“A robot is a reprogrammable multi-functional manipulator designed to move material, parts, tools or specialised devices through variable programmed motions for the performance of a variety of tasks.”** Robots have come in a big way in the task of moving, transferring and

manipulating materials in between operations as well as during some specialised operations. An industrial Robot has three principal components:

- i) One or more arms, usually situated in a fixed base, that can move in several directions
- ii) A manipulator, being the “hand” that holds the tool or the part to be worked
- iii) A controller that gives detailed movement instructions.

Robotics is helping continuous flow processes to changeover from one output to another since the material handling equipment, which was earlier designed as part of a production or assembly line, can now be independently programmed.

c) CAD/CAM/CAE

This trilogy of terms stands for computer aided design (CAD), computer aided manufacturing (CAM) and computer aided engineering (CAE). In these systems, the computer aids in the design process by providing different images of the designed product from different view—the computer screen acting as the designer's drawing board. The CAM ties the NC machines with the material handling equipment so the manufacturing operations are working together. In CAE, the computer is used to aid in analysing engineering problems, particularly structured analysis where the structure has previously been designed using CAD. In its widest sense, these imply the automation using computer control of all activities necessary to take a product from concept to its completed manufacture.

d) Flexible Manufacturing

Current usage of the term flexible manufacturing relates to automated manufacture. Traditionally, automation in manufacturing has been possible only for high volume low variety products where the production process adopted had been of the continuous flow process form. Such process had suffered from inflexibility—not only in terms of output characteristics but also of output rate. In flexible manufacturing an attempt is made to introduce flexibility not only in terms of component design but also operation sequence, batch sizes and overall production capacity. Flexible manufacturing tries to combine the advantages of conventional automation with the strategic advantages attached to intermittent processing viz increased variety, improved response to customer orders, updated product designs etc.

2.11 PROCESSING INDUSTRIES

The processing industries e.g., fertiliser, petrochemicals, petroleum, milk and drugs, etc. also use continuous processing. However, they deserve a special

mention as they differ from organisations producing either discrete products or services. In general, the operations in these organisations are highly automated with very sophisticated controls, often electronic or computerised. The labour requirements are generally low and the role of the production workers is limited to monitoring and taking some corrective action if necessary. However, maintenance of equipment is very critical and the skills required in maintenance are of high order.

A Single Input

In processing industries, there is usually a single principal input material which is processed into one or more different products. In discrete manufacturing, on the other hand, there are many different input materials which are processed and assembled to form the product.

Analytic and Synthetic Processes In an analytic process, a single input is processed into many separate outputs. A typical example would be a petroleum refinery, where the single input, viz. petroleum is processed into petrol, diesel, naphtha, furnace oil and a host of other intermediates. In a synthetic process, on the other hand, many different inputs are synthesised into one output. For example hydrogen, sulphur and oxygen are combined together to make sulphuric acid. Processing industries generally use analytic processes whereas continuous flow processing in discrete manufacturing generally use synthetic processes.

Continuous Processing

In spite of the differences mentioned above, there is a basic similarity in the concept as well as the approach followed in both flow shops and the processing industries — only the variety in outputs is nil so far as processing industries are concerned. Because of this, automation could be carried out to its physical limits and the process is designed for a specific mix of outputs. The result is that initial set up of equipment and procedures is even more complex and critical than for continuous flow processing.

2.12 SELECTION OF THE PROCESS

In this section we would address ourselves to the issue of selecting the appropriate process form or mix of forms for an organisation to produce its output. The details are involved in the actual designing and laying out of the transformation processes, the laying out of the workplaces, the designing of the planning and control procedures and the assurance of quality, etc. These are the subject matter of the complete course and would be taken up later in other units.

Combination of Process Forms

The four forms of processing that we have referred to earlier, are really four simplified extremes of what is likely to be observed in practice. We will find

very few organisations using only one of these processing forms in its pure sense. In fact by alluding to concepts like group technology and flexible manufacturing we have referred to systems which attempt to combine the advantages of two or more of these pure forms.

Most organisations combine two or more of these process forms to produce different components and the final product. In many industries including automobiles, domestic electrical appliances etc. the components are made using the intermittent form of processing whereas the final assembly is based on continuous flow processing.

Production of Services

Like products, services could also be produced using different process forms. Although the intermittent processing form has been the typical form used for services, services as those provided by a lawyer are more like project processes. Again, by standardising the outputs and consequently increasing the volume of standard outputs, many services are now produced using the continuous flow process form. We have already given the example of fast food service in this context. Another example comes from Russia where a flowline has been used for routine eye surgery whereby patients are literally passed along a line from one surgeon to another, each of whom performs a small part of the total operation. We are, therefore, slowly coming to realise that services can be mass produced.

Product/Process Life-cycles

In Units 1 and 2 we have referred to the life-cycle which a typical output undergoes — from its introduction through growth, maturity and decline phases. There is a similar life-cycle for the process used to produce the output. Figure V can be interpreted to show that the product and the process life cycles are related.

When an output is just introduced, it is made in small volumes in an inefficient, uncoordinated manner which might start using the project form. However, very soon it is produced in small batches using the intermittent processing form. As the output goes through the growth phase, more and more sub-processes are designed using the continuous flow processing form. Finally, in the maturity phase, the product competes mostly on price. The volumes are high and highly cost efficient methods are required to produce the product at a low cost. The continuous flow processing form is then the most suitable form of process.

Break-even Analysis For Process Forms

The progress along the process life-cycle is shown below in Figure VII using break-even analysis for each of the process forms. At the introduction stage, the product is first produced with little or no commitment of equipment and facilities using mostly labour intensive methods. The process form used is the project form and most of the cost is variable cost including the cost of labour.

As the product passes on the growth phase, general purpose machines and equipment are organised into the intermittent form to produce the output in a flexible manner. Finally, when the continuous flow processing form is used towards the maturity phase of the product life-cycle, the fixed costs of operation are very high and the variable cost per unit of output is quite low. Figure VII also shows the least cost process at any stage of the life-cycle (heavy line) and it can be easily seen that as volumes rise, a different form of process might become the least cost alternative.

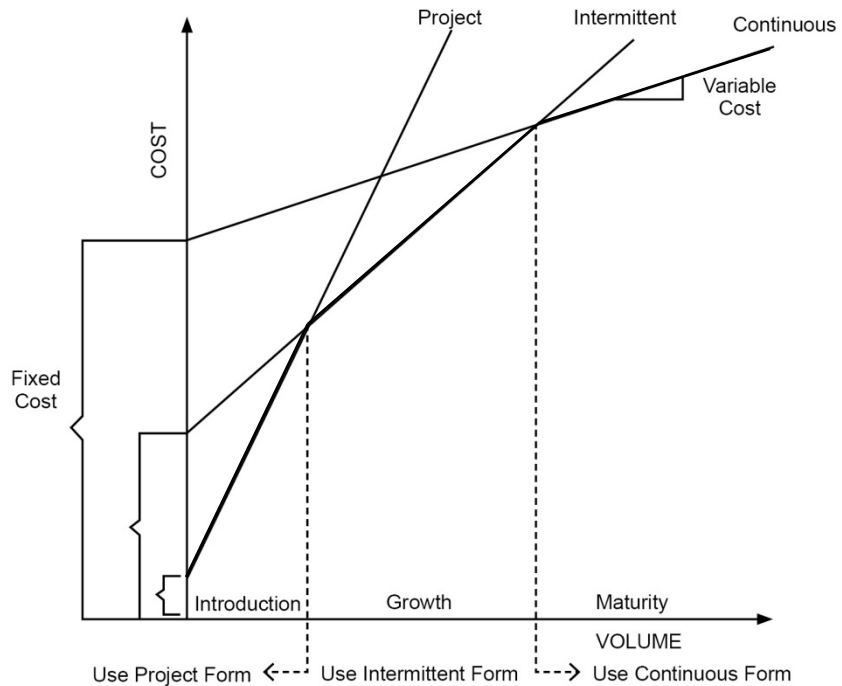


Figure VII: Break-even analysis of process from selection with phases of life-cycle.

Maintaining the Focus

The point to note is that the process form adopted should evolve as the market and the output evolve. If a company feels that its competitive strength lies in having a flexible production system which can respond very fast to specific customer needs, then as the outputs move into another phase of their life-cycle in which a different process form is preferable, it drops the output or licenses it to someone else and switches to another output more appropriate to its competitive strengths.

Each factory or office should have a clearly defined focus in its operations and the process form adopted is one of the key elements that creates the focus. It is not possible to have a production system which can satisfy all sorts of demands made on it — e.g., fast response to changes in output design, low cost of production, high capacity utilisation of resources, and so on.

2.13 SUMMARY

We have looked at the processes of bringing new product and services to the market in this unit and the role of operations in that process. We identified all outputs of an organisation as services, sometimes along with a facilitating good and sometimes without that. Product selection is a strategic decision for the organisation and the top management as well as functions like marketing, R & D and engineering have a role in the making of product selection decisions.

We looked at the stages involved in bringing new output from an idea stage into a tangible entity in the market. New product ideas are generated through market research, research laboratories themselves or conscious, formalised attempts. These ideas have a very high mortality and the new idea mortality curve showed that hardly 1 or 2 percent of all new ideas are carried through to the market.

New product ideas are first screened for market viability and their fit with corporate strengths and weaknesses. These are then subjected to an economic analysis. New product ideas are then developed, features are added or dropped, variations introduced and the product is finally designed and tested for a commercial bunch.

Product designs attempt to introduce a product having characteristics as close to what is desired by the customers as possible and this involves tradeoffs between elements like the function, cost, quality, reliability and others like producibility, maintainability, product safety and environmental impact, etc. We found that product innovations and process innovations are closely linked to the life-cycle of the product itself.

We have looked at the various process forms that can be used to effect transformation of inputs into outputs. Having established the strategic nature of process selection decisions, we explored the various considerations which affect the process selection. The major consideration in choosing an appropriate process form is the output characteristics in terms of its volume and variety. A related consideration is whether the output is produced-to-stock (push production) or produced-to-order (pull production).

When the output is produced in very low volumes and the output variety is large, the project form of transformation is often the most appropriate. Project processes have short life-cycles and need a high level of coordination so that in spite of strict precedence relationships between activities, the project is not delayed beyond its scheduled date of completion.

For low volume high variety output, the intermittent flow processing form offers the advantage of flexibility at reasonable cost, whereas for high volume low variety outputs, the continuous flow processing form is often used. We have looked at the characteristics of these process forms in great

detail and also discussed the advantages and disadvantages of each of these. We have also mentioned some of the new technologies for each of these process forms.

When the output has no variety, and if it is a commodity, the processing form offers great cost savings by using highly automated transformation processes where the role of production workers is only to monitor the processes and take corrective action, if needed.

We have noted that most organisations adopt a combination of different process forms. Just like products, even services can be mass produced if the variety can be reduced giving rise to high volumes.

2.14 KEY WORDS

Producibility: of an output refers to the ease and speed with which the output can be produced.

New-Idea Mortality Curve: shows in a graphical form the number of output ideas surviving after each of several hurdles till the ideas get converted to outputs and enter the market.

Product Design: It is defined as a visible and tangible expression of an idea and the design process originates from a set of requirement and moves through idea generation and product selection.

Product Development: Refers to modifications or extensions provided to ideas so as to improve the functioning, the cost and the value-for-money of the product.

Standardisation: attempts reduction in variety and better use of productive facilities, thereby achieving lower unit costs.

Modularisation: involves designing the output using modules that are interchangeable and each different combination of modules gives a new variety of the output.

Product: is used here in its generic sense and is meant to include services; same as output.

Output Ideas: refer to ideas regarding possible new outputs which, after refinements and modifications, could result in some outputs offered in the market.

Screening: the process of establishing the market viability of a new output idea as well as to find the desirability of adding the new output to the outputs of the organisation.

An adaptive process: A process which has to continually adapt to many external factors.

Assembly Line When only assembly operations are performed on a line it is called an assembly line.

Produce-to-Stock: A production policy which allows products to be produced and stocked in our warehouse and sold as and when demand occurs.

Produce-to-order: A production policy which allows outputs to be produced only on receipt of an order from the customer.

Project form of processing: Used to produce an output which is one of a kind.

Reaction time Time required for an organisation or a system to react to a change either internal or external.

Matrix organisation: A form of organisation structure in which a dual system of grouping is adopted, e.g., a person is assigned to a project which he or she retains membership of the functional organisation.

Intermittent form of processing: When the output variety is large, the production facilities are organized specialisation-wise, thus making the material flow non-uniform, zig-zag and intermittent.

Flexibility: refers to the ease with which a productive facility can be used to produce different outputs.

In-process inventory: The stock of semi-finished products usually required to cushion the effect of unequal production rates and to balance the high set up cost for some operations

Group technology: Attempts to find groups of component parts, machines, equipment and people which can be exploited while organising the team formation process.

Line balancing: Implies that each work station in a production or an assembly line has an equal work content so that no work station has an idle time, nor does it have bottlenecks.

NC or numerical control refers to the use of some form of electronic system for automating machines and process,

Flexible manufacturing is the approach towards making automated manufacture flexible both in terms of output characteristics and output rate.

Analytic process: In an analytic process, a single input is processed into many separate outputs

Synthetic process: In a synthetic process, many different inputs are synthesised into one output.

2.15 SELF-ASSESSMENT EXERCISES

- 1) There are many stages involved in bringing a new output to the market. Why can't the stages be performed in a smooth sequence?
- 2) Give examples of some organisations where you feel the new-idea mortality rates would be low. Why?
- 3) Can services be standardised? Should they be standardised?

- 4) How should an organisation balance the different design characteristics in a new product?
- 5) What are the important factors to be considered while finding the 'fit' of an output to an organisation?
- 6) Explain the Product Selection and stages involved therein.
- 7) What is producibility? How does it affect product selection?
- 8) "Product development and design is basically a research and development activity". Elaborate the statement with suitable examples.
- 9) Explain Product design. How does it influence the Process Design?
- 10) Discuss with suitable examples the process of launching a new product in the market.
- 11) The equipment used in intermittent flow shops is less specialised than that used in continuous flow shops. What about the labour?
- 12) Can flexibility or economy be obtained only at the cost of each other?
- 13) Why do you think is managing a high-volume continuous operation easier than managing a high-variety intermittent operation ?
- 14) Explain why the in-process inventory is likely to be higher for an intermittent operation than for a continuous flow operation?

2.16 FURTHER READINGS

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UNIT 3 FACILITIES LOCATION

Objectives

After going through this unit, you should be able to:

- understand the strategic importance and objectives of facilities location, realise the enlarged scope of dealing with facility rather than just plant/factory location and identify various factors relevant for general territory selection as well as those relevant for specific site/community selection
- appreciate that the location decisions are quite complex because of the existence of subjective intangible factors along with objective tangible factors, be in a position to apply some relevant technique either subjective, qualitative or semi-quantitative in nature and grasp some simple operational research oriented models
- realise the need for recognition of the assumptions and limitations of the quantitative models discussed, provide a blend of some good rational qualitative judgment and the analytical model solutions and be in a position to identify relevant factors for facility location.

Structure

- 3.1 Introduction
- 3.2 When does a Location Decision Arise?
- 3.3 Steps In the Facility Location Study
- 3.4 Subjective, Qualitative and Semi-Quantitative Techniques
- 3.5 Locational Break-Even Analysis
- 3.6 Some Quantitative Models for Facility Location
- 3.7 Some Case Examples
- 3.8 Summary
- 3.9 keyword
- 3.10 Self assessment Exercises
- 3.11 Further Reading

3.1 INTRODUCTION

Facility location decisions are strategic, long term and non-repetitive in nature. Without sound and careful location planning in the beginning itself, the new facility may pose continuous operating disadvantages, for the future operations. Location decisions are affected by many factors, both internal and external to the organisation's operations. Internal factors include the technology used, the capacity, the financial position, and the work force required. External factors include the economic political and social

conditions in the various localities. Most of the fixed and some of the variable costs are determined by the location decision. The efficiency, effectiveness, productivity and profitability of the facility are also affected by the location decision. The facilities location problem is concerned primarily with the best (or optimal!) location depending on appropriate criteria of effectiveness. Location decisions are based on a host of factors, some subjective, qualitative and intangible while some others are objective, quantitative and tangible.

Concept of a facility

Traditionally, location theorists have dealt with industrial plant/factory location. However, the concept of **plant location** has now been generalised into that of **facility location**, since the facility could include a production operation or service system.

The term 'Plant' has been traditionally used as synonymous to a factory, manufacturing or assembly unit. This could include fertiliser, steel, cement, rice milling plants, textile, jute, sugar mills, rubber factories, breweries, refineries and thermal or hydro-electric nuclear power stations etc.

However, with the enlarged scope of a facility, this term can now be used to refer to banks, hospitals, blood banks, fire stations, police stations, warehouse, godown, depot, recreation centre and central repair workshop etc. At a lower hierarchical level is the facility/plant layout problem which will be discussed in the next unit. In such a case machines, equipment, desks, workshop, canteen and emergency room etc. could mean a facility. Thus, in fact, we could generally state that a facility could connote almost any physical object relevant to location analysis. Let us now see when a location decision arises.

3.2 WHEN DOES A LOCATION DECISION ARISE?

The impetus to embark upon a facility location study can usually be attributed to various reasons:

- i) It may arise when a new facility is to be established.
- ii) In some cases, the facility or plant operations and subsequent expansion are restricted by a poor site, thereby necessitating the setting up of the facility at a new site.
- iii) The growing volume of business makes it advisable to establish additional facilities in new territories.
- iv) Decentralisation and dispersal of industries reflected in the Industrial Policy resolution so as to achieve an overall development of a developing country would necessitate a location decision at a macro level.

- v) It could happen that the original advantages of the plant have been outweighed due to new developments.
- vi) New economic, social, legal or political factors could suggest a change of location of the existing plant.

Some or all the above factors could force a firm or an organisation to question whether the location of its plant should be changed or not.

Whenever the plant location decision arises, it deserves careful attention because of the long term consequences. Any mistake in selection of a proper location could prove to be costly. Poor location could be a constant source of higher cost, higher investment, difficult marketing and transportation, dissatisfied and frustrated employees and consumers, frequent interruption of production, abnormal wastages, delays and substandard quality, denied advantages of geographical specialisation and so on. Once a facility is set up at a location, it is very difficult to shift later to a better location because of numerous economic, political and sociological reasons.

Economic reasons could include total costs, profits, availability of raw materials, labour, power, transportation facilities and markets etc. Social reasons could include employee welfare, employment opportunities etc. Political reasons could be because of pursuance of a policy of decentralisation, regional and developmental planning especially in a developing country like ours. There could be security considerations or risk of military invasions, sabotage from anti-social elements etc. and some may be prone to natural calamities like floods, earthquake etc. Policy matters like anti-pollution etc. would have to be given their due consideration.

Weber's Analysis.

Alfred Weber's analysis was one of the first attempts to base location decisions on some sort of analysis, its imperfections notwithstanding. Besides discussing the importance of transport and labour cost differentials in deciding location, the main burden of Weber's analysis is transport cost of raw material which was least mobile

On the basis of availability, he categorised raw materials into: (a) **ubiquities-**to denote those available almost everywhere like sand, water etc. and (b) **localised materials**, having specific locations, which are further divided into pure material which contributes nearly the total weight of it to the finished goods, and gross material, which contributes only a small fractions of total weight to the finished goods. It is obvious that ubiquities hardly influence the decision of location. Weber then proceeds to formulate the material index which equals the weight of localised material used in the finished product divided by the weight of the finished product.

$$\text{Material Index (MI)} = \frac{\text{Weight of localised material used in finished product}}{\text{Weight of the finished product}}$$

If $MI \geq 1$ then the location should be nearer to the source of raw material

If $MI < 1$ then the location should be nearer to the market.

The commonsense involved in such conclusion is unquestionable. But such an approach tacitly assumes the existence of a static point of lowest transportation cost for raw material.

Later analyses by various other authors, like, Weigman, Palander, Losch, Ohlin and others have been attempted on increasingly comprehensive bases such as the interrelationship between factors like, (a) economic differences-(prices, market), (b) cost differences-(productivity, transport cost and accessibility), (c) human differences-(attitudes of founders and wage-earners), (d) national characteristics, and (e) various barriers-(political, geographic and transportation). Let us now see how a location study is made.

3.3 STEPS IN THE FACILITY LOCATION STUDY

Location studies are usually made in two phases namely, (i) the general territory selection phase, and (ii) the exact site/community selection phase amongst those available in the general locale. The considerations vary at the two levels, though there is substantial overlap as shown in Table 1.

Table 1: Overlap of considerations of factors in the two stages of facility location

Location Factors		Phase I General Territory Selection	Phase II Particular Selection of Site and Community
1	Market	•	
2	Raw Materials	•	
3	Power	•	•
4	Transportation	•	•
5	Climate and Fuel	•	
6	Labour and Wages	•	•
7	Laws and Taxation	•	•
8	Community Services and Attitude		•
9	Water and Waste		•
10	Ecology and Pollution		•
11	Capital Availability	•	•
12	Vulnerability to enemy attack	•	•

A Typical team studying location possibilities for a large project might involve economists, accountants, geographers, town planners, lawyers, marketing experts, politicians, executives, industrial engineers, defence

analysts and ecologists etc. It is indeed an inter-disciplinary team that should be set up for undertaking location studies.

Territory Selection – Phase I

Now in step (i) for the general territory/region/area selection, the following are some of the important factors that influence the selection decision.

- a) **Markets:** There has to be some customer/market for your product/service. The market growth potential and the location of competitors are important factors that could influence the location. Locating a plant or facility nearer to the market is preferred if promptness of service required, if the product is fragile, or is susceptible to spoilage. Moreover, if the product is relatively inexpensive and transportation costs add substantially to the cost, a location close to the markets is desirable.

Assembly type industries also tend to locate near markets.

- b) **Raw Materials and Supplies:** Sometimes accessibility to vendors/suppliers of raw materials, parts supplies, tools, equipment etc. may be very important. The issue here is promptness and regularity of delivery and inward freight cost minimisation.

If the raw material is bulky or low in cost, or if it is greatly reduced in bulk viz transformed into various products and by-products of it is perishable and processing makes it less so, then location near raw materials sources is important. If raw materials come from a variety of locations, the plant/facility may be situated so as to minimise total transportation costs. The costs vary depending upon specific routes, mode of transportation and specific product classifications.

- c) **Transportation Facilities:** Adequate transportation facilities are essential for the economic operation of a production system. For companies that produce or buy heavy bulky and low value per ton commodities, water transportation could be an important factor in locating plants. It can be seen that civilisations grew along rivers/waterways etc. Many facilities/plants are located along river banks.
- d) **Manpower Supply:** The availability of skilled manpower, the prevailing wage pattern, living costs and the industrial relations situation influence the location.
- e) **Infrastructure:** This factor refers to the availability and reliability of power, water, fuel and communication facilities in addition to transportation facilities.

Legislation and Taxation: Factors such as financial and other incentives for new industries in backward areas or no-industry-district centres,

exemption from certain state and local taxes and octroi etc. are important.

- f) **Climate:** Climatic factors could dictate the location of certain type of industries like textile industry which requires high humidity zones.

Site/Community Selection – Phase II

Having selected the general territory/region, next we would have to go in for site/community selection. Let us discuss some factors relevant for this stage.

- a) **Community Facilities:** These involve factors such as quality of life which in turn depends on availability of facilities like schools, places of worship, medical services, police and fire stations, cultural, social and recreation opportunities, housing, good streets and good communication and transportation facilities.

- b) **Community Attitudes:** These can be difficult to evaluate. Most communities usually welcome setting up of a new industry especially since it would provide opportunities to the local people directly or indirectly. However, in case of polluting, or 'dirty' industries, they would try their utmost to locate them as far away as possible.

Sometimes because of prevailing law and order situation, companies have been forced to relocate their units. The attitude of people as well as the state government has an impact on industrial location.

- c) **Waste Disposal:** The facilities required for the disposal of process waste including solid, liquid and gaseous effluents need to be considered. The plant should be positioned so that prevailing winds carry any fumes away from populated areas and so that waste may be disposed off properly and at reasonable expense.

- d) **Ecology and Pollution:** These days there is a great deal of awareness towards maintenance of natural ecological balance. There are quite a few agencies / propagating the concepts to make the society at large more conscious of the dangers of certain avoidable actions.

- e) **Site Size:** The plot of land must be large enough to hold the proposed plant and parking and access facilities and provide room for future expansion. These days a lot of industrial areas/parks are being earmarked in which certain/standard sheds are being provided to entrepreneurs. (especially small scale ones).

- f) **Topography:** The topography, soil structure and drainage must be suitable. If considerable land improvement is required, low priced land might turn out to be expensive.

- g) **Transportation Facilities:** The site should be accessible by road and rail preferably. The dependability and character of the available transport

carriers, frequency of service and freight and terminal facilities are also worth considering.

- h) Supporting Industries and Services:** The availability of supporting services. such as tool rooms and plant services etc. need to be considered
- i) Land Costs:** These are generally of lesser importance as they are non-recurring and possibly make up a relatively small proportion of the total cost of locating a new plant. Generally speaking, the site will be in a city, suburb or country location. In general, the location for large-scale industries should be in rural areas, which helps in regional development also. It is seen that once a large industry is set up (or even if a decision to this effect has been taken), a lot of infrastructure develops around it as a result of the location decision. As for the location of medium scale industries, these could be preferably in the suburban/semi-urban areas where the advantages of urban and rural areas are available. For the Small-scale Industries, the location could be urban areas where the infrastructural facilities are already available. However, in real life, the situation is somewhat paradoxical as people, with money and means, are usually in the cities and would like to locate the units in the city itself.

Some of the industrial needs and characteristics that tend to favour each of these locales are now discussed. **Requirements**, governing choice of **a city location** are:

- 1) Availability of adequate supply of labour force,
- 2) High proportion of skilled employees.
- 3) Rapid public transportation and contact with suppliers and customers.
- 4) Small plant site or multi floor-operation.
- 5) Processes heavily dependent on city facilities and utilities.
- 6) Good communication facilities like telephone, telex and post offices.
- 7) Good banking and health care delivery systems.

Requirements governing the choice **of a suburban location** are:

- 1) Large plant site close to transportation or population centre.
- 2) Free from some common city building zoning (industrial areas) and other restrictions.
- 3) Freedom from higher parking and other city taxes etc.
- 4) Labour force required resides close to plant.
- 5) Community close to, but not in, large population centre.
- 6) Plant expansion easier than in the city.

Requirements governing the choice **of a country/rural location** are:

- 1) Large plant site required for either present demands or expansion.

- 2) Dangerous production processes.
- 3) Lesser effort required for anti-pollution measures.
- 4) Large volume of relatively clean water.
- 5) Lower property taxes, away from Urban Land Ceiling Act restrictions.
- 6) Protection against possible sabotage or for a secret process.
- 7) Balanced growth and development of a developing or underdeveloped area.
- 8) Unskilled labour force required.
- 9) Low wages required to meet competition.

3.4 SUBJECTIVE, QUALITATIVE AND SEMI-QUANTITATIVE TECHNIQUES

Three subjective techniques used for facility location are Industry Precedence, Preferential Factor and Dominant Factor. Most of us are always looking for some precedents. So in the industry precedence subjective technique, the basic assumption is that if a location was best for similar firms in the past, it must be the best for us now. As such, there is no need for conducting a detailed location study and the location choice is thus subject to the principle of precedence-good or bad. However in the case of the preferential factor, the location decision is dictated by a personal factor. It depends on the individual whims or preferences e.g. if one belongs to a particular state, he may like to locate his unit only in that state. Such personal factors may override factors of cost or profit in taking a final decision. This could hardly be called a professional approach though such methods are probably more common in practice than generally recognised. However, in some cases of plant location there could be a certain dominant factor (in contrast to the preferential factor) which could influence the location decision. In a true dominant sense, mining or petroleum drilling operations must be located where the mineral resource is available. The decision in this case is simply 'whether to locate or not at the source'.

For evaluating qualitative factors, some factor ranking and factor weight rating systems may be used. In the ranking procedure, a location is better or worse than another for the particular factor. By weighing factors and rating locations against these weights, a semi-quantitative comparison of location is possible. Let us now discuss some specific methods.

Equal Weights Method

We could assign equal weights to all factors and evaluate each location along the factor scale. For example, Banson, a manufacturer of fabricated metal products selected three factors by which to rate four sites. Each site was assigned a rating of 0 to 10 points for each factor. The sum of the assigned

factor points constituted the site rating by which it could be compared to other sites.

Table 2: Decision Matrix

Factor ↓	Potential Sites →	S ₁	S ₂	S ₃	S ₄
F ₁		2	5	9	2
F ₂		3	3	8	3
F ₃		6	2	7	3
Site Rating		11*	10	24	8
Sample Calculation		11*	2+3+6		

F₁ = Factor 1, S₁ = Site 1....etc.

Looking at Table 2, Site 3 has the highest site rating of 24. Hence, this site would be chosen.

Variable Weights Method

The above method could be utilised on account of giving equal weightage to all the factors. Hence, we could think of assigning variable weights to each of the factors and evaluating each location site along the factor scale. Hence, factor F_i might be assigned 300 points, factor 2 might be assigned 100 points and factor 3 might be assigned 50 points. Thus the total points scored, out of the maximum assigned to each of the factors, for each possible location site could be obtained and then the site with the highest score would be the obvious choice.

Table 3: Decision .Matrix

Factor	Max. Pts.	Potential Sites			
		S ₁	S ₂	S ₃	S ₄
F ₁	(300)	200	250	250	50
F ₂	(100)	50	70	80	100
F ₃	(50)	5	50	10	40
Site Rating		255*	370	340	190

*Sample Calculation 255 = 200 + 50 + 5

Looking at the Table 3, Site 2 has the highest site rating of 370. Hence, this site would be chosen.

Weight-cum-Rating Method

We could have yet another method of evaluating a potential location site. We could assign variable weights to each factor. The locations are then rated by a common scale for each factor. The location point assignment for the factor is then obtained by multiplying the location rating for each factor by the factor

weight. For example, rating weights of 1 to 5 could be assigned to the three factors F_1 (Labour climate), F_2 (community facilities) and F_3 (power availability and reliability), as 5, 3, 2 respectively. Now for each of the factors, sites S_1 , S_2 , S_3 , or S_4 they could receive 0 to 10 points as shown below. Now each site rating could be obtained.

Table 4: Decision Matrix

Factor	Factor Rating Weights	Potential sites			
		S_1	S_2	S_3	S_4
F_1	5	2	5	9	2
F_2	3	3	3	8	3
F_3	2	6	2	7	3
Site Rating :		31*	38	83	25

*Sample Calculation $31 = (5) \times 2 + (3) \times 3 + (2) \times 6$

As shown in Table 4, the sample calculation should hopefully suffice to obtain the site ratings. Here, site S_3 with the highest rating of 83 is chosen.

Factor-Point Rating Method

Now for a last one, establish a subjective.- scale common to all factors. Assign points against the subjective scale for each factor and assign the factor points of the subjective rating for each factor. For example, five subjective ratings—Poor, Fair, Adequate, Good and Excellent were selected to be used in evaluating each site for each factor (F_1 , F_2 and F_3). For each of these factors, 'adequate' was assigned a value zero and then negative and positive weights were given to each factor F_1 (water supply), F_2 (appearance of site) and F_3 (supply of labour) (say) as shown in Table 5.

Table 5: Factor Point Ratings Sample

	Poor	Fair	Adequate	Good	Excellent
Factor F_1 , water Supply	-15	-12	0	6	10
F_2 Appearance of site	-3	-1	0	1	2
F_3 Supply of labour	-4	-2	0	2	4

The range between minimum and maximum weights assigned to a factor in effect weighs that factor against all other factors in a manner equivalent to the method (iii) described just previous to this one. Each location site S_1 , to S_4 , were then rated by selecting the applicable subjective rating for each factor for each location and the equivalent points of that subjective 'factor rating assigned to the factor. Thus we can now obtain Table 6.

Table 6: Decision Matrix

Factors	Potential Sites			
	S ₁	S ₂	S ₃	S ₄
F ₁	(Adequate) 0	(Fair) -12	(Good) 6	(Adequate) 0
F ₂	(Adequate) 0	(Poor) -3	(Excellent) 3	(Fair) -1
F ₃	(Adequate) 0	(Adequate) 0	(Adequate) 0	(Adequate) 0
Site Rating	0	-15*	9	-1

Sample Calculation - 15* = (-12) + (-3) + (0)

Accordingly Site 3 with the maximum score of 9 will be chosen.

In most cases, hardly any attempt is made to establish a direct relationship between the site rating point value and the cost values. Usually, this is left to the management

The location analyst presents to management both the cost and the intangible data results. In such cases, management could take a decision based on a simple composite measure method illustrated below with the aid of a numerical example.

Composite Measure Method

Let us enlist the steps of the composite measure method

Step-1 Develop a list of all relevant factors.

Step-2 Assign a scale to each factor and designate some minimum.

Step-3 Weigh the factors relative to each other in light of importance towards achievement of system goals.

Step-4 Score each potential location according to the designated scale and multiply the scores by the weights.

Step-5 Total the points for each location and either (a) use them in conjunction with a separate economic analysis, or (b) include an economic factor in the list of factors and choose the location on the basis of maximum points.

Now let us illustrate the composite measure method with a numerical example. There are three potential sites and five relevant factors like transportation costs per week, labour costs per week, finishing material supply, maintenance facilities and community attitude. The costs are in rupees whereas for the last three factors, points are assigned on 0-100 scale. The data collected is shown in Table 7 below.

Table 7: Payoff Matrix

Factors	Potential Location Sites			
	F ₁	S ₁	S ₂	S ₃
Transportation cost/ week (Rs.)		800	640	580
Labour cost/week (Rs.)	F ₂	1180	1020	1160
Finishing Material Supply	F ₃	30	80	70
Maintenance Facilities	F ₄	60	20	30
Community Attitude	F ₅	50	80	70

The location analyst has pre-established weights for various factors. This includes a standard of 1.0 for each Rs. 10 per week of economic advantage. Other weights applicable are 2.0 on finishing material supply, 0.5 on maintenance facilities and 2.5 on community attitudes. Also the organisation prescribes a **minimum acceptable score of 30 for maintenance facilities**.

First of all let us look at the economic factors F₁, and F₂ for which monetary values were possible. If we total the costs for each site, we get the costs for sites S₁, S₂ and S₃ as Rs. 1980, Rs. 1660 and Rs. 1740, respectively. Thus site S₁ would be the worst cost wise. Site S₂ would have an economic advantage over site S₁ to the extent of Rs. (1980 - 1660) = Rs. 320. Similarly, site S₃ would have an economic advantage over site S₁ to the extent of Rs. (1980 - 1740) = Rs. 240. Now the monetary value in Rs. can be converted to a point scale as you would realise that a standard of 1.0 is to be assigned for each Rs. 10 per week of economic advantage. Thus we could get the following Table 8.

Table 8: Decision Matrix

Factor	Weightage	Potential Location Sites		
		S ₁	S ₂	S ₃
Combine (F ₁ + F ₂) Economic Advantage	1.0	0	32	24
F ₃	2.0	30	80	70
F ₄	0.5	60	20	30
F ₅	2.5	50	80	70
Composite Site Rating		*215	402	354
*Sample calculation *215 = (1.0) × 0 + 2.0 × 30 – 1 – 0.5 × 60				

Now on referring to certain prerequisites for certain factors, because of the nature of the situation., a constraint in the form of a site scoring of at least 30 on account of maintenance had been given. You would be able to observe that this basic requirement is not met by site S₂ though its score is the highest at 402. Hence the next best score of 354 by S₃ satisfying the constraint of at least 30 on maintenance, is the obvious choice. Site S₃ is chosen finally.

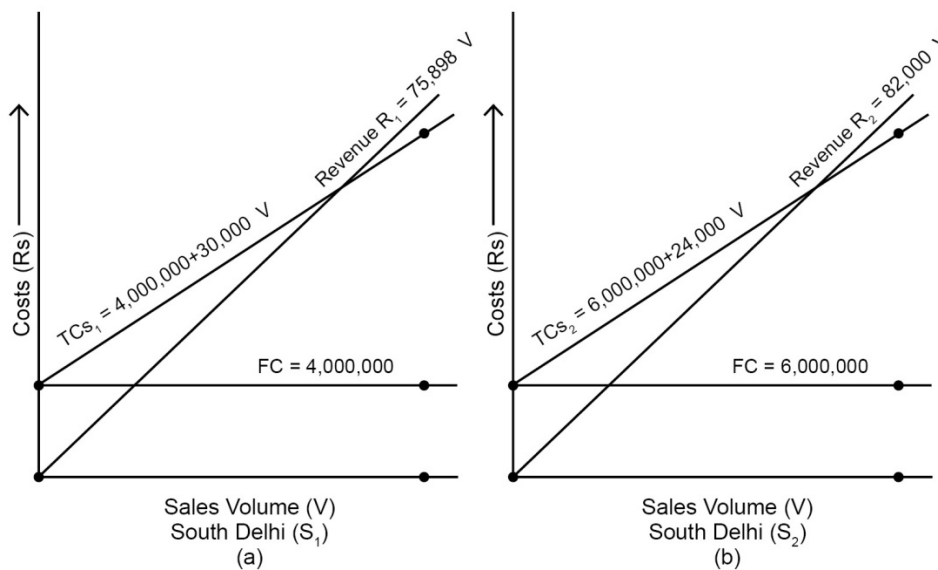
3.5 LOCATIONAL BREAK-EVEN ANALYSIS

Sometimes, it is useful to draw location break-even charts which could aid in deciding which location would be optimal. The location of a Tractor factory in a South Delhi site will result in certain annual fixed costs, variable costs and revenue. The figures would be different for a South Bombay site. The fixed costs, variable costs and price per unit for both sites are given below in Table 9.

Table 9: Cost Data

Location Site	Fixed Costs	Variable Costs per unit	Price per Unit
South Delhi (S ₁)	40,00,000	30,000	75,898
South Bombay (S ₂)	60,00,000	24,000	82,000

Let us assume that the expected sales volume as estimated by a market research team is 95.



The data of Table 9 is depicted pictorially in Figure I showing the location break- even charts. Now the break-even point is defined to be the point or volume where the total costs equal total revenue. Thus for each site S₁ and S₂, the break-even point can be determined by using a simple formula (which could be easily derived) as follows:

$$\text{Break-even Volume (BE)} = \frac{\text{Fixed Costs}}{(\text{Revenue per Unit} - \text{Variable Cost per Unit})}$$

At the South Delhi Location S₁

$$\text{BE} = \frac{40,00,000}{75,898 - 30,000} = 87.1497 = 88 \text{ tractors}$$

and at the South Bombay location S₂

$$BE = \frac{60,00,000}{82,000 - 24,000} = 103.448 = 104 \text{ tractors}$$

Let us see what would be the profit or loss for the two sites at the expected volume of 95 Units. The calculations are shown in Table 10.

Table 10: Cost Comparisons

South Delhi (S ₁)			South Bombay (S ₂)		
Cost			Cost		
	Fixed	40,00,000		Fixed	60,00,000
	Variable	28,50,000		Variable	22,80,000
		68,50,000			82,80,000
Revenue			Revenue		
	75,898 × 95 = 72,10,310			82,000 × 95 = 77,90,000	
Profit	= (72,10,310 - 68,50,000)		Loss	= (77,90,000 - 82,80,000)	
	= 1,80,155			= 4,90,000	

Now what do we find? The South Delhi (S₁) site is preferable, even though the revenues are lower, since the Company will lose money by locating the plant in south Bombay (S₂).

3.6 SOME QUANTITATIVE MODELS FOR FACILITY LOCATION

Various types of quantitative models (or operations research models) have been used to help determine the best facilities location. Let us describe a few models that are simple to understand and powerful enough to give some good answers that could aid you in taking a location decision.

Median Model

Let us discuss the simple median model which is based on the assumption that the mode of interaction or the path of movement/transportation of load is done on a rectangular/rectilinear pattern. The movement is similar to the movement of 'rooks' on a chess board. Thus all movements are made horizontally along and east-west and/or vertically in a north-south direction.

Diagonal moves are not considered.

D_r = Rectilinear Distance Between a new facility P(X,Y) and an ancillary existing facility A(a_i,b_i)

$$= |X - a_i| + |Y - b_i|$$

$$(TC) \text{ Total Transportation Cost} = \sum_{i=1}^m L_i \times D_i \times \text{Cost/unit distance/unit load}$$

Where L_i is the number of loads to be moved between the new facility to be located and the ancillary existing ith Facility (say raw material sources or

market distribution outlet points), D_i is the rectilinear distance between a new facility and i th existing facility and m is the number of ancillary existing facilities.

Thus as a location analyst, we essentially want to determine the least transportation cost location solution. The simple median model can help answer this question by using these three steps.

- i) Identify the median value of the total number of loads moved.
- ii) Find the X-Coordinate value of the existing facility that sends (or receives) the median load and
- iii) Find the Y-coordinate value of the existing facility that sends (or receives) the median load.

The X and Y values found in steps (ii) and (iii) define the desired optimal (best) location of the new facility.

The Gravity Model

The technique determines the low cost 'Centre of Gravity' location of a new facility with respect to the fixed ancillary existing facilities like source suppliers (S_1, S_2 etc.) and distribution points (D_1, D_2 , etc.) for which each type of product consumed or sold is known. The only difference between the Median model and the Gravity model is that the mode of interaction between the single new facility and the existing facilities. In this case we assume that all goods move in straight line joining the ancillary facilities and the new facilities. This is so-called 'Euclidean' mode of interaction and is in fact the shortest distance between the two reference points. The diagonal movements are allowed here.

Thus $D_e = \text{Euclidean Distance} = [(X - a_i)^2 + (Y - b_i)^2]^{1/2}$

$TCE(\text{Total transportation cost})(\text{Euclidean case})$

$$= \sum_{i=1}^m L_i [(X - a_i)^2 + (Y - b_i)^2]^{1/2} \times \text{cost / unit distance / unit load}$$

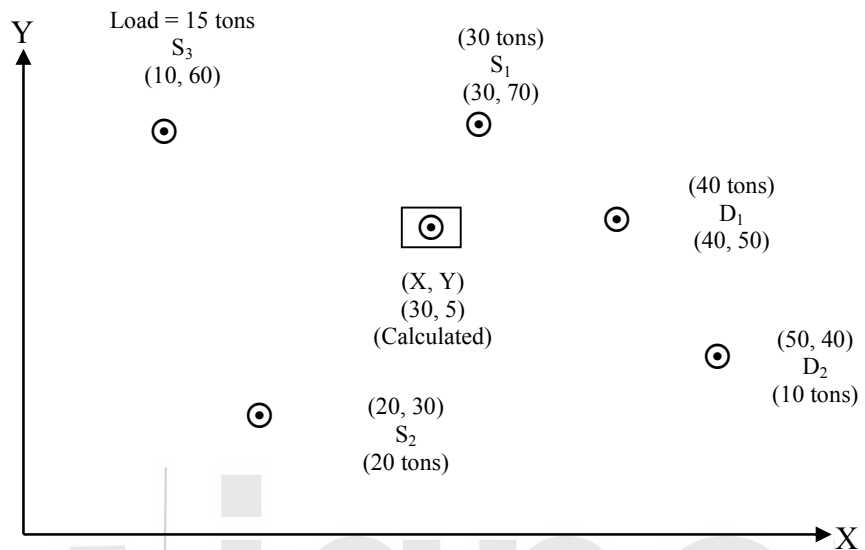
The value of X and Y can be calculated as follows

$$x = \frac{\sum_{i=1}^m L_i (a_i)}{\sum_{i=1}^m L_i} \text{ and } y = \frac{\sum_{i=1}^m L_i (b_i)}{\sum_{i=1}^m L_i}$$

The application of median model and gravity model will be illustrated in the following Example.

Example 3.1 A new processing point is to be located which will be receiving certain raw materials from three supply sources S_1, S_2 and S_3 and will be sending its finished products to two distribution points D_1 and D_2 . The coordinate locations of the sources and distribution points and loads are

shown in Fig II. Find out the best location of the new processing point by using both median model and gravity model and also find out the total cost of transportation for the above two models if the rate is rupees 2 per unit distance per ton of load.



Solution-Median Model

Total load moved = 30 + 20 + 15 + 10 + 40 = 115 tons

The median number of loads is the value that has half an equal number of loads above and below it which is equal to $\frac{115+1}{2} = 58$ tons.

Next put the X-coordinate of existing facilities in Ascending Order, these are:

S ₃	S ₂	S ₁	D ₁	D ₂
(10, 60)	(20, 30)	(30, 70)	(40, 50)	(50, 40)
(15t)	(20t)	(30t)	(40t)	(10t)

Loads 1t to 15t are shipped from S₃ at x₃ = 10

Loads 16t to 35t are shipped from S₂ at x₂ = 20

Loads 36t to 65t are shipped from S₁ at x₁ = 30

Since the median load 58t falls in the interval 36t to 65t, therefore X = 30 (X-coordinate of the new facility).

Again put the Y-coordinates of existing facilities in Ascending order, these are:

S ₂	D ₂	D ₁	S ₃	S ₁
(20, 30)	(50, 40)	(40, 50)	(10, 60)	(30, 70)
(20t)	(10t)	(40t)	(15t)	(30t)

Loads 1t to 20t are shipped from S₂ at y₂ = 30

Loads 21t to 30t are shipped to D₂ at y'₂ = 40

Loads 31t to 70t are shipped to D₁ at y'₁ = 50

Since median load 58t falls in the interval 31t to 70t, therefore $Y = 50$ (Y-coordinate for the new facility)

Transportation cost from S_1 to new facility

$$= 30\{|X - x_1| + |Y - y_1|\} \times 2 = 30\{|30 - 30| + |50 - 70|\} \times 2 = 30 \times 20 \times 2 = \text{Rs. } 1200$$

Transportation cost from S_2 to new facility = Rs. 1200

Transportation cost from S_3 to new facility = Rs. 900

Transportation cost from new facility to D_1 = Rs. 800

Transportation cost from new facility to D_2 = Rs. 600

Total cost = Rs. 4700

The median model is very simple to operate but it could suffer from the following disadvantages:

- It assumes that only one single new facility is to be located.
- Every point in the (x, y) plane has been assumed to be an eligible point for the location of the new facility. (There may be some restriction or constraints at some point in the x - y plane)
- The median model is valid when the movement is based on a rectilinear mode only.

Gravity Model

$$X = \frac{x_1 \times \text{Load}_1 + x_2 \text{Load}_2 + x_3 \text{Load}_3 + \dots}{\text{Load}_1 + \text{Load}_2 + \text{Load}_3 + \dots}$$

$$= \frac{10 \times 15 + 20 \times 20 + 30 \times 30 + 40 \times 40 + 50 \times 10}{15 + 20 + 30 + 40 + 10}$$

$$= \frac{3550}{115} = 30.87$$

$$Y = \frac{y_1 \times \text{Load}_1 + y_2 \times \text{Load}_2 + y_3 \times \text{Load}_3 + \dots}{\text{Load}_1 + \text{Load}_2 + \text{Load}_3 + \dots}$$

$$= \frac{60 \times 15 + 30 \times 20 + 70 \times 30 + 50 \times 40 + 40 \times 10}{15 + 20 + 30 + 40 + 10}$$

$$= \frac{6000}{115} = 52.17$$

$$PQ = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

Transportation cost = $\Sigma \text{load} \left\{ \sqrt{(X - x_i)^2 + (Y - y_i)^2} \right\} \times \text{Rs. } 2 / \text{unit dist} / \text{ton}$

$$= \left[30\sqrt{(30.87 - 30)^2 + (52.17 - 70)^2} + 20\sqrt{(30.87 - 20)^2 + (52.17 - 30)^2} \right. \\ \left. + 15\sqrt{(30.87 - 10)^2 + (52.17 - 60)^2} + 40\sqrt{(30.87 - 40)^2 + (52.17 - 50)^2} \right. \\ \left. + 10\sqrt{(30.87 - 50)^2 + (52.17 - 40)^2} \right] \times 2$$

$$= [30 \times 17.85 + 20 \times 24.69 + 15 \times 22.29 + 40 \times 9.38 + 10 \times 22.67] \times 2$$

$$= (535.50 + 493.80 + 334.35 + 375.20 + 226.70) \times 2 = 1965.55 \times 2$$

$$= \text{Rs. } 3931.10 < \text{Rs. } 4700 \text{ of median model.}$$

It will be seen that for the same data of the problem, gravity model provides less transportation cost compared to median model.

You would have noticed that we have only discussed the location problems dealing with just a single new facility and also what is termed as a **minisium** objective of minimising the sum weighted appropriate distances. There could be cases when the location as determined above turn out to be non-feasible, because of existence of certain restrictions or limitations. Methods are available for drawing iso-cost contour lines which aid the decision maker to take subsequent appropriate decisions. Sometimes a minimax objective might be more suited in which case the location analyst attempts to minimize the maximum weighted appropriate distances. Such a criterion would be applicable in emergency like facility location problems of fire stations, hospitals etc. Minisium objective situations are appropriate for locating factories and warehouses etc.

You would have observed that facilities location decision is based on a set of factors some of which are tangible/objective whereas some others are intangible/ subjective in nature. Objective Factors are those that can be evaluated in inventory terms such as labour, raw materials, utilities and taxes etc. Subjective Factors are characterized by a qualitative type of measurement. For example the nature of community support may be evaluated but its monetary equivalent cannot be established. Similarly research climate, recreation and entertainment, housing and community attitude etc. are also subjective factors. **Brown and Gibson** have proposed a composite location measure to aid the decision makers.

Composite Location Measure Model – 2 (Brown Gibson Model)

Let us now discuss Brown Gibson Model which provides a composite location measure of the objective and subjective factors. We illustrate the procedure with the help of an example with some steps.

Step – 1

First of all identify the factors that deserve to be included in the study and determine which of these must be absolutely satisfied, e.g, there is no point in choosing a site having scarcity of water whereas the plant requires an abundant water supply. Rest of the steps will be explained in the solution to the **Example 3.2**

Example 3.2 (Brown Gibson Model) We have the following data for the three possible sites 1,2 and 3 with annual cost(in thousand of Rs) for each in respect of labour , marketing ,utilities and taxes:

Site (i)	Labour	Marketing	Utilities	Taxes	Total C_i
1	248	181	74	16	519
2	211	202	82	8	503
3	230	165	90	21	506

The subjective factors for the sites include housing, recreation and competition. We deal with the subjective intangible factors with the help of a forced pair-wise comparison rating method. The procedure is applied to rank the importance of the factors I_k (I_k is the **Property weight** – weight of a subjective factor k relative to all subjective factors, $(0 \leq I_k \leq 1)$) first and is then applied to each site to rate how well the site satisfies the factors S_{ik} (S_{ik} is the **site weight** – weight of the site i relative to all potential sites for subjective factors k , $0 \leq S_{ik} \leq 1$). These two ratings are combined to obtain the subjective factor (SFi) ranking for each site as $SFi = \sum(I_k \cdot S_{ik})$. The factor comparison is shown in pairs. If one factor is preferred over the other, the one preferred is given 1(one) point whereas the other factor is given 0(zero) point. If one is indifferent between the two factors, 1(one) point each can be assigned as seen in decision 3 while comparing factor B and C in Table 11 and likewise in Tables 12,13 and 14.

You are required to make selection for the most preferred site.

Solution: Step 2... Let us derive an objective factor (OF_i) for the i th location site by multiplying that site's rupees cost (C_i) by the sum of reciprocal of all the costs $\sum(1/C_i)$ and take the inverse of the product $OF_i = [C_i \times \sum(1/C_i)]^{-1}$

We have $\sum(1/C_i) = 1/519 + 1/503 + 1/506 = 0.005891$

$OF_1 = (519 \times 0.005891)^{-1} = 0.3271$

$OF_2 = (503 \times 0.005891)^{-1} = 0.3374$

$OF_3 = (506 \times 0.005891)^{-1} = 0.3355$

Step 3.. Now we shall deal with the subjective factors I_k and S_{ik}

Table 11 (Determination of I_k)

Factor	Comparison Decision			Sum of preferences	Factors Rating (I_k)
	1	2	3		
A: Housing	1	1	-	2	$2/4 = 0.50$
B: Recreation	0	-	1	1	$1/4 = 0.25$
C: Competition	-	0	1	1	$1/4 = 0.25$
				Total = 4	Total = 1.0

Table 12: Factors A-Housing

Site	Decision			Total	S _{Ak}
	1	2	3		
1	1	0	-	1	1/3=0.33
2	0	-	0	1	0
3	-	1	1	2	2/3=0.67

Table 13: Factor B-Recreation

Site	Decision			Total	S _{Bk}
	1	2	3		
1	0	0	-	0	0
2	1	-	1	2	0.67
3	-	1	0	1	0.33

Table 14: Factor C-Competition

Site	Decision			Total	S _{Ck}
	1	2	3		
1	1	0	-	1	0.25
2	1	-	0	1	0.25
3	-	1	1	2	0.50

Table 15: Summary of subjective factors

Site	Site Rating			Importance
	1	2	3	
A	0.33	0	0.67	0.50
B	0	0.67	0.33	0.25
C	0.25	0.25	0.50	0.25

We can now calculate the subjective factor value SF_i for each site as follows:

$$SF_1 = (0.50) \times (0.33) + (0.25) \times (0) + (0.25) \times (0.25) = 0.2275$$

$$SF_2 = (0.50) \times 0 + (0.25) \times (0.67) + (0.25) \times (0.25) = 0.2300$$

$$SF_3 = (0.50) \times (0.67) + (0.25) \times (0.33) + (0.25) \times (0.50) = 0.5425$$

Step 4.. Now depending upon the parties concerned, would depend the objective factor decision weight (X) which is given to the objective versus subjective factors. Objective factors being more important than subjective ones, we give a 2/3 weightage to objective and only 1/3 weightage to subjective factors i.e. X=0.67.

The value of X may be varied according to the situation of objective & subjective factors such as availability of raw materials, labour, utilities and extent of taxes levied and environmental condition, research climate, housing facilities and community attitude etc.

The composite location measures (LM_i) = (X) (OF_i) + (1 – X) (SF_i)

$$\text{We have } LM_1 = 0.67 \times 0.3271 + 0.33 \times 0.2275 = 0.29433$$

$$LM_2 = 0.67 \times 0.3374 + 0.33 \times 0.2300 = 0.30203$$

$$LM_3 = 0.67 \times 0.3355 + 0.33 \times 0.5425 = \mathbf{0.4038 \text{ (max)}}$$

Obtaining the maximum score of 0.4038, **site 3 is the obvious preferred site.**

A model that attempts to deal with multidimensional location problem can be developed based on multiattribute preference theory. We present here a modification of model developed by Brown and Gibson in the year 1972.

Example 3.3 (Brown Gibson modified model) (see Buffa and Sarin 2016 Modern production/Operations Management, Wiley India Pvt.ltd.New Delhi.

The following table shows the various subjective factors of the six possible sites along with their annual costs in thousands of rupees. You are required to determine the most preferred site amongst the six sites mentioned below.

Site	Objective factor cost(OF _i) in thousand Rs	Availability of Transportation	Availability of labour	Managerial control	Support of community
1	3.0	Good	Good	Fair	High
2	5.5	Excellent	Fair	Good	Very high
3	4.1	Good	Good	Excellent	Good
4	3.5	Low	Very Good	Good	Low
5	3.9	Good	Fair	Very Good	High
6	3.2	Very Good	Excellent	Very Good	Very High

Solution: The objective factor measure for site i, OF_i in terms of the objective function costs is defined as follows:

$$OF_i = \frac{\text{Maximum OF} - OF_i}{\text{Maximum OF} - \text{Minimum OF}}$$

For example for site 3 we have $OF_3 = (5.5 - 4.1) / (5.5 - 3.0) = 0.56$

Similarly $OF_1 = 1.00$, $OF_2 = 0.00$, $OF_4 = 0.80$, $OF_5 = 0.64$ and $OF_6 = 0.92$

The subjective factor measure $SF_i = \sum (I_k \cdot S_{ik})$ where I_k is the **property weight** – weight of subjective factors k relative to all subjective factors, S_{ik} is the **site weight** – weight of the site i relative to all sites for subjective factor k.

Assumptions – As per the opinion of the manager incharge of the project and also by group consensus, the percentage contribution of the subjective factors and also the rating scale of these factors have been finalized as below :

	% Contribution		Rating scale
Availability of transportation	= 20 %	Very high/Excellent	= 1.00
Availability of labour	=30%	High/Very Good	= 0.75
Managerial control	= 30%	Good	= 0.50
Support of community	= 20%	Fair	= 0.25
		Low	= 0.00

Objective Factors Decision Weight (X) is taken to be equal to 0.67

Calculation of Subjective Factor Measure (Table 16)

Site	Availability of transportation (0.20)	Availability of labour (0.30)	Managerial control (0.30)	Support of community (0.20)	Subjective factor measure
1	0.50	0.50	0.25	0.75	0.340*
2	1.00	0.25	0.50	1.00	0.625
3	0.50	0.50	1.00	0.50	0.650

4	0.00	0.75	0.50	0.00	0.375
5	0.50	0.25	0.75	0.75	0.550
6	0.75	1.00	0.75	1.00	0.875

$$*0.2 \times 0.50 + 0.3 \times 0.50 + 0.3 \times 0.25 + 0.2 \times 0.75 = 0.340$$

Location Measure for six sites(X=0.67 taken) **Table 17**

Site	Objective factor measure	Subjective factor measure(From Table 15)	Location measure
1	1.00	0.340	0.782**
2	0.00	0.625	0.206
3	0.56	0.650	0.590
4	0.80	0.375	0.660
5	0.64	0.550	0.611
6	0.92	0.875	0.905(Max)

$$**0.67 \times 1.00 + 0.33 \times 0.340 = 0.782$$

Site 6 produces the largest overall location measure and hence this **Site 6 is the preferred choice.**

Note : The decision for the choice of scale and relative importance of the subjective factors is commonly based on managerial judgement that requires a careful analysis of the trade-off between cost and combined effect of the dictating factors.

Bridgeman's Dimensional Analysis: The comparison and selection of a site is very easy in case all the costs were tangible and quantifiable and the least cost site would have been the obvious choice. In most cases, however, there are many intangible costs which may be better expressed in relative terms rather than absolute terms. For example, educational facilities for children or lack of it at a site is difficult to quantify in absolute term but relative merits/demerits of two alternative sites can be compared more easily. One site may be said to have a facility twice as good as the other site. Since both tangible and intangible costs need to be considered for the selection of a site, a procedure of comparing relative merit of alternative sites requires to be worked out and **Bridgeman's Dimensional Analysis** is the answer.

It consists in computing the relative merits (or cost ratios) for each of the cost items giving every ratio an appropriate weightage by means of the power (index) raising and then multiplying these weighted ratio together to come up with a comprehensive figure. This figure gives the relative merit of the two alternate sites. Thus if X_{11}, X_{12}, X_{13} are the different costs associated with site M and X_{21}, X_{22}, X_{23} are the different costs associated with site N and $w_1, w_2, w_3, \dots$ are the weightages given to these items, then the relative merit of site M and site N is given by .

$$R_{MN} = \left(\frac{X_{11}}{X_{12}} \right)^{w_1} \times \left(\frac{X_{21}}{X_{22}} \right)^{w_2} \times \left(\frac{X_{31}}{X_{32}} \right)^{w_3} \dots$$

If $R_{MN} > 1$ then site N is superior

If $R_{MN} < 1$ then site M is superior

The examples that follow would make understanding quite clear.

A five point scale for dimensional analysis is developed for Research Climate, Labour Supply, Community Attitude and Community Services. The scores range from 1 to 5 **from the best to the worst conditions**. The scores could be determined by the manager incharge of the project and by the group consensus. The decision is commonly based on managerial judgement that requires a careful analysis of the trade-off between the cost and the combined effect of the subjective and the objective factors.

Dimensional- Analysis Scale

(Intangible Factor)

Research Climate

Point

No schools, research organization or societies exist

5

A few low quality schools and nothing else

4

Good research organization but nothing else

3

Good schools, research group and societies.....

2

Excellent research climate

1

Labour Supply

None available

5

Limited Supply at premium rates.....

4

Acceptable supply for now but doubtful for future.....

3

Adequate supply of acceptable ability.....

2

Plentiful supply of excellent ability

1

Community Attitude

Active pressure groups against company activity

5

Will accept company activity with reservations.....

4

Ambivalent

3

Cooperative.....

2

Very cooperative, encouraging and helpful.....

1

Community Services

Practically no picture halls or marketing malls	5
Only a few entertainment places for name sake.....	4
Good sources of amusement and pass-time.....	3
Better malls, big bazars, cinema hall etc.....	2
Excellent places for enjoyments like parks, community centers etc.	1

Example 3.4 The following dimensional analysis is given for selecting the best site out of the two with their tangible and intangible factors. Select the preferred one by Bridgeman's Analysis.

Factor	Site		Weight
	M	N	
Labour	Rs. 1,50,000	Rs. 1,00,000	1
Power	Rs. 40,00,000	Rs. 25,00,000	1
Educational facilities	2	6	2
Community attitude	2	4	2

Solution: Relative cost of site M to site N is

$$R_{MN} = \left(\frac{1,50,000}{1,00,000} \right)^1 \times \left(\frac{40,00,000}{25,00,000} \right)^1 \times \left(\frac{2}{6} \right)^2 \times \left(\frac{2}{4} \right)^2$$

$$= 0.066 < 1.00 \text{ so site M is preferred.}$$

Although the tangible costs for site M are higher than those for site N, the effect of the intangibles is seen to be overwhelming. In practice such things do happen. There are many reasons other than quantifiable costs which go into the choice making between alternate sites. However when such choice is important from the national or social point of view, then choice of the intangibles and weightages attached to them assumes a critical importance.

Example 3.5 The intangible and tangible figures for the three sites S₁, S₂ and S₃ are given below in a tabular form. Make out your calculations by Bridgeman's Dimensional Analysis to select the best site out of the three.

Factors	Sites			Weight
	S ₁	S ₂	S ₃	
Building cost and Equipment cost(Rs.)	25,00,000	15,00,000	20,00,000	4
Taxes per year (Rs)	2,50,000	1,00,000	1,80,000	4
Power cost per year Rs.	1,00,000	1,50,000	1,20,000	4
Community attitude	2	4	3	1
Labour Supply	4	6	5	3
Research Climate	5	30	20	2

$$R_{12} = \left(\frac{25}{15}\right)^4 \times \left(\frac{25}{10}\right)^4 \times \left(\frac{10}{15}\right)^4 \times \left(\frac{2}{4}\right)^1 \times \left(\frac{4}{6}\right)^3 \times \left(\frac{5}{30}\right)^2 = 0.045 < 1 \text{ hence site 1 is better than 2}$$

$$R_{13} = \left(\frac{25}{20}\right)^4 \times \left(\frac{25}{18}\right)^4 \times \left(\frac{10}{12}\right)^4 \times \left(\frac{2}{3}\right)^1 \times \left(\frac{4}{5}\right)^3 \times \left(\frac{5}{20}\right)^2 = 0.092 < 1 \text{ hence site 1 is better than 3}$$

$$R_{23} = \left(\frac{15}{20}\right)^4 \times \left(\frac{10}{18}\right)^4 \times \left(\frac{15}{12}\right)^4 \times \left(\frac{4}{3}\right)^1 \times \left(\frac{6}{5}\right)^3 \times \left(\frac{3}{2}\right)^2 = 0.378 < 1 \text{ hence site 2 is better than 3}$$

From the above analysis, we conclude that the overall choice is site 1.

Recent Trends in Facility location

The following most important trends have come to fore recently with regards to plant location.

- 1) To locate the plant away from cities.
- 2) Development of industrial estates.
- 3) Competition among states to develop industries.
- 4) Trends towards decentralization.
- 5) Pollution control
- 6) Location of industries leading to balanced regional development
- 7) Growth of multinational firms thereby transcending the geographical area of the country

3.7 SOME CASE EXAMPLES

By now we have had quite an exposure to qualitative, semi-qualitative, quantitative and analytical techniques which could aid in taking a proper location decision. A location decision is quite a difficult and complex problem especially in the context of a developing country like ours which has a large variety of problems.

Most of the factory workers are found in Delhi, Mumbai, Kolkata, Surat, Ahmedabad and Ludhiana. A few years back a number of factories were in the above cities where more than 67% share of total industrial capital was invested and more than 63% share of industrial workers was engaged. The distribution of industrial activity in the country had been extremely uneven because of concentration and centralization of the workers in these cities only.

Such tendencies of centralization are because of factors of agglomeration. Agglomeration refers to the advantages gained due to production being made less expensive on account of the concentration of industries. In the industrial field, one can easily note the clustering/grouping together (localization of the jute industry in West Bengal and Textile Industry in Mumbai, Ahmedabad and Surat). However, if due to any reason, the industrial unit is either unsuccessful or some difficult labour problems crop up, then there are a lot of subsequent hardships. Also with the point of a view of war and safety, the

concentration of industry might not be a wise decision. The concentration of industry leads to the accumulation of unreasonable amount of workers which in turn creates crowded conditions, pollution explosion, housing and schooling problems etc.

After independence, the government is trying to bring about a regional balance in industrial location as reflected in the Industrial Policy resolutions that favour dispersal/decentralisation (because of the advantages of deglomeration factors). Balanced growth of all the areas or judicious dispersion of facilities in all the regions enables the nation to utilise both human and physical resources more effectively and efficiently. Agricultural, mineral and other resources can properly be tapped.

Moreover, employment opportunities would be more equitably distributed.

The North-Eastern Region has now being given its due consideration. Several problems of a socio-economic nature such as, acute shortage of housing and essential food materials, spread of epidemics, diseases and gambling etc. arise due to the creation of slums. The slums can hopefully be reduced by proper dispersion of industries. The people come to cities in search of employment. This migration could be checked provided the right opportunities are provided at the right time at their local places.

Let us see where some industries other than the jute and textile industries which prefer a climate having high humidity are located.

Steel Plants: We find that most of the steel plants lie along the Bihar and Bengal, Orissa belt. In the manufacture of steel, it is always economical to transport the finished product rather than the raw material inputs like coal, lime-stone and iron ore because during production considerable weight reduction is involved. There also exists a port based steel plant at Vishakhapatnam, which in addition to taking advantage of proximity of iron-ore and coal also avails of the port facilities which aids in importing plant and machinery during the construction phase of the steel plant and in exporting the finished products when the plant goes into production run.

Cement Plants: Again in the case of cement manufacturing plants, the raw materials lose weight significantly in the process of transformation, and so the cement plants are located near the lime stone and coal deposits.

Fertiliser Industry: The main feed stocks for the fertiliser industry are gas, oil or naphtha and coal. Here again the fertiliser plants are located near the source of raw materials. The locations of fertiliser plants at Namroop and Thal Vaishet based on gas, and those at Ramagundam, Talcher and Sindri based on coal are examples. In the case of naphtha or oil based plants most of the feed stock required is imported and hence, the plants are located near the ports.

Mangalore Fertilizers at Mangalore, Madras Fertilizers at Chennai, FACT at Cochin and Hindustan Fertilisers at Haldia are the relevant location examples.

Machine-tool Industries: Unlike the previous cases discussed, in the machine-tool industry case, the proximity to the source of raw material is not very significant. A number of other factors such as market factors and infrastructure will come into the picture. The machine tool industry is scattered over different parts of the country such as Bangaluru, Mumbai, Kolkata and Ludhiana etc.

Nuclear Power Stations: The selection and evaluation of sites of nuclear power plants throughout the world have become increasingly difficult in recent years as pressure from various societal segments has resulted in strict consideration of the institutional environmental, safety, socio-economic and engineering factors affecting the siting, construction and operation of such facilities. A comprehensive site selection process presents a formidable task to the decision makers. The site selection methodology combines selective screening to narrow down the search area and a classification and rating scheme to rank siting possibilities in order of preference for detailed consideration.

The basic procedural steps used in the selective screening policy are summarised below:

- a) Countrywide screening — land availability, water availability and seismotectonic areas,
- b) Candidate regions screening — hydrology, geology, land use, meteorology, accessibility, transmission lines, demography and topography.
- c) Candidate siting areas screening — ecology and other factors as in (b) above.

This concludes the regional' approach heading to an aggregate of possible sites to be evaluated in detail for their suitability to host a nuclear power plant facility.

Basic siting considerations are, Institutional (required service data, system reliability requirements), Engineering (safety, geology, hydrology, meteorology), Environmental (ecological sensitivity), Economic (Land cost, cooling system alternatives) and Socio-economic (land owner dislocations, community attitude and public acceptance).

Many electric generating facilities have been located along the banks of rivers so as to strategically utilise readily available cooling water for plant condenser needs. It is important to plan for effluent disposal so as to minimise pollution whether it be in the air, water or soil and also to make schemes to arrest the notorious noise intensity.

3.8 SUMMARY

In this unit we have dealt with an important strategic long term and non-repetitive problem namely the facilities location problem. The traditional factory/plant location concept has enlarged to include non-manufacturing enterprises and service industries etc. You would have realised that facilities location depends on a large number of factors, some concerned with the general territory selection whereas some other factors that are relevant for site/community selection. A large number of methods are proposed that include subjective, qualitative, semi-quantitative and quantitative models for facility location. Locational break-even analysis is also an aid. Weights and ratings of factors are discussed; a median model for the single facility rectilinear model and a gravity model for the Euclidean norm have been outlined. Some composite location measure models like the Brown and Gibson's model and the Bridgeman's dimensional analysis have also been explained. At the end, some case examples of different types of requirements for site, location for steel plant, cement mill and fertilizer factory etc. have been discussed.

3.9 KEY WORDS

Agglomeration: Refers to advantages gained in production due to centralisation/ concentration of industries.

Deglomeration is the antithesis of Agglomeration. It leads to a reduction in the cost of production due to decentralisation.

Euclidean norm: The shortest path obtained by joining the reference points by a straight line.

Facility: A facility could connote any physical object, be it a factory, hospital or bank, relevant to location analysis.

Location of a facility: Geographic site at which a productive facility is suited between the two reference points.

Minisium objective: An objective whereby the location analyst wishes to minimise the sum of weighted appropriate distances between all relevant reference points.

Rectilinear norm: A path obtained by either moving horizontally or vertically between the two reference points.

3.10 SELF-ASSESSMENT EXERCISES

- 1) A manufacturer of farm equipment is considering three locations (P, Q and R) for a new plant. Cost studies show that fixed costs per year at the sites are

Rs. 4,80,000, Rs. 5,40,000 and Rs. 5,04,000, respectively whereas variable costs are Rs. 100 per unit, Rs. 90 per unit and Rs. 95 per unit, respectively. If the plant is designed to have an effective system capacity of 2,500 units per year and is expected to operate at 80 per cent efficiency, what is the most economic location? If the operational efficiency that can be obtained is only 60, what effect would this have on the site you had determined earlier on?

[i) Site P (ii) Still Site P]

- 2) An equipment supplier has collected the following data on possible plant locations. Costs are in Rs per year

	Site P	Site Q	Site R
Rent and utilities	Rs. 20,000	Rs. 24,000	Rs. 30,000
Taxes	4,000	3,000	2,000
Labour	1,90,000	1, 60,000	1, 80,000
Materials	2,60,000	2,64,000	2,54,000
Community service	Good	Poor	Average
Community attitude	Indifferent	Indifferent	Favourable

If you were responsible for making the decision on the basis of the information given above, which site would you select and why?

Hint: Follow example 3.3 $OF_P = (474-474) / (474-451) = 0$, $OF_Q = 1$, $OF_R = 0.348$

Subjective factor measure : poor – 0; Average/indifferent-1; Good/favourable – 2

Subjective Factor measure				Location measure			
Site	C. service 50% taken	C. attitude 50% taken	Subjective factor measure	Site	OF (x=0.67)	SF (0.33)	Location measure
P	2	1	1.5*	P	0	1.5	0.495**
Q	0	1	0.5	Q	1	0.5	0.835
R	1	2	1.5	R	0.348	1.5	0.728
1.5* = $2 \times 0.50 + 1 \times 0.50$				0.495** = $0 \times 0.67 + 1.5 \times 0.33$			

Location measure score of Q is the highest, but because community service(poor) and community attitude (indifferent), both the subjective factors are in bad shape at this site, it cannot be recommended to be selected.

So the **next preferred site is R**

- 3) Discuss the factors that influence the location of a plant with particular reference to Mathura Petroleum Refinery. Do you justify such a decision?
- 4) It is generally felt that "rural areas are good for locating large plant, semi-urban areas for locating medium-sized plants, and urban areas for small-scale plants". Comment.

- 5) A particular city is trying to find the best location for a master solid waste disposal station. At present four substations are located at the following coordinate locations: station 1 (4, 12), station 2 (6.5, 4) station 3 (11, 9) and station 4 (1, 13).

The number of loads hauled monthly to the master station will be 300, 200, 350 and 400 from stations 1, 2, 3 and 4, respectively.. Use the simple median model to find the best location. [$X=4, Y=12$, Haulage cost= $7200p$ (where p = each distance unit cost per load)]

- 6) For the data given in exercise 5, what would be the best location in case the gravity model is used? Which do you think is the appropriate model to apply in the above situation-median or gravity model?

[$X=5.4, Y=10.2, TC=6037.50p$ (gravity) < $7200p$ and gravity model preferred]

- 7) What are the steps of a facility location study? In case you want to locate a soft drink bottling plant, what factors would you consider relevant for taking a location decisions? How would you go about conducting the location study?

- 8) The following table gives information about the existing facilities of a beverage company

Facility (F)	Coordinate location (x, y)	Cost of moving one unit by unit distance (Rs.)	Annual load (L) Units
Bareilly	10, 80	10	452
Shahjahanpur	30,60	10	678
Gonda	80. 50	10	483
Kanpur	50, 10	10	711
Sultanpur	80, 10	10	539

The company wants to locate a new facility such that the total transportation cost is the minimum. Find out the new location and the minimum cost by using Median model and Gravity model.

[(Median (50,50), $TC = \text{Rs. } 13,26,400$
Gravity (49.66, 39.64), $TC = \text{Rs. } 10,40,130$)]

- 9) Udhampur Distilleries Ltd has four existing facilities A. B. C and D. The details of these facilities are given the table below : It is desired by the company to locate a new facility such that the total transportation cost is the minimum. Advise the company about the best possible location using the Median model and the gravity model. Also find the total transportation cost.

Existing Facility (F)	Annual loads between F and new facility (units)	Cost of moving one unit by unit distance (Rs.)	Coordinate location (x, y)
A	279	10	20,30
B	473	10	70,10
C	350	10	50,40
D	266	10	10,80

(Median (50,30), $TC = R < 5,47,5000$

Gravity (43,36), $TC = Rs. 3,84,900$)

- 10) Consider a problem in which a single facility out of the three alternatives must be located location A in Mumbai, B in Delhi and C' in Kolkata. The following six factors are seen as the ones which should e.ume the decision, cost of land, cost of building, taxes, labour supply, research climate and community attitudes (details for which given below).

Factor	A	B	C	weight
land Cost (Rs.)	6,00,000	3,00,000	4,50,000	5
Building Cost (Rs.)	10,00,000	8,00,000	9,00,000	5
Taxes (Rs.)	8,00,000	5,00,000	6,50,000	5
labour supply	2	1	3	3
Research Climate	1	2	2	2
Community attitudes	3	1	3	3

Which one is your preferred choice? (use Bridgeman's Dimensional Analysis).

[($R_{AB} > 1$, B is superior to A; $R_{AC} > 1$, C is Superior to A; $R_{BC} < 1$, B is Superior to C. Hence B is the preferred Location)]

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UNIT 4 FACILITIES LAYOUT AND MATERIALS HANDLING

Objectives

After going through this unit, you should be able to

- Appreciate different types of layout problem, become familiar with the basic types of plant layouts and the factors to be considered for layout design and comprehend the procedure for designing the layouts in a systematic manner
- Understand different kinds of tools that can be used for the analysis of material flow and activities in a plant, realise how the space is estimated and allocated for different work centres and the facilities and know the use of computerised techniques for designing the layouts.
- Learn how to evaluate, specify, present and implement a layout, identify the factors that should be considered in the selection of material handling system, become familiar with different types of material handling equipments used in plant design and appreciate the integrated approach to layout planning and material handling system design and the role of automation in plant design.

Structure

- 4.1 Introduction
- 4.2 Basic Types of Plant Layouts
- 4.3 Plant Layout Factors
- 4.4 Layout Design Procedure
- 4.5 Flow and Activity Analysis
- 4.6 Space Determination and Area Allocation
- 4.7 Computerised Layout Planning
- 4.8 Evaluation, Specification, Presentation and Implementation
- 4.9 Materials Handling Systems
- 4.10 Materials Handling Equipment
- 4.11 Summary
- 4.12 Key Words
- 4.13 Self-assessment Exercises
- 4.14 Further Readings

4.1 INTRODUCTION

Importance and Function

Facilities layout refers to an optimum arrangement of different facilities including man, machine, equipment, material etc. Since a layout once implemented cannot be easily changed and costs of such a change are substantial, the facilities layout is a strategic decision. A poor layout will result in continuous losses in terms of higher efforts for material handling, more scrap and rework, poor space utilisation etc. Hence, need to analyse and design a sound plant layout can hardly be over emphasised. It is a crucial function that has to be performed both at the time of initial design of any facility, and during its growth, development and diversification.

The problem of plant layout should be seen in relation to overall plant design which includes many other functions such as product design, sales planning, selection of the production process, plant size, plant location, buildings, diversification etc. The layout problem occurs because of many developments including:

- change in product design
- introduction of new product
- obsolescence of facilities
- changes in demand
- market changes
- competitive cost reduction
- frequent accidents
- adoption of new safety standards
- decision to build a new plant

Plant layout problem is defined by Moore (1962) as follows:

“Plant layout is a plan of, or the act of planning, an optimum arrangement of facilities, including personnel, operating equipment, storage space, materials- handling equipment, and all other supporting services, along with the design of the best structure to contain these facilities.”

Objectives and Advantages

Some of the important **objectives of a good plant layout** are as follows:

- i) Overall simplification of production process in terms of equipment utilisation, minimisation of delays, reducing manufacturing time, and better provisions for maintenance.
- ii) Overall integration of man, materials, machinery, supporting activities and any other considerations in a way that result in the best compromise.

- iii) Minimisation of material handling cost by suitably placing the facilities in the best flow sequence.
- iv) Saving in floor space, effective space utilisation and less congestion/confusion.
- v) Increased output and reduced inventories-in-process.
- vi) Better supervision and control.
- vii) Worker convenience, improved morale and worker satisfaction.
- viii) Better working environment, safety of employees and reduced hazards.
- ix) Minimisation of waste and higher productivity
- x) Avoid unnecessary capital investment
- xi) Higher flexibility and adaptability to changing conditions.

Types of Layout Problems

The facilities layout problems can be classified according to the types of facility under consideration e.g.

- i) Manufacturing Plants
- ii) Commercial facilities, e.g., shops, offices, Bank etc.
- iii) Service facilities, e.g., Hospitals, Post Offices etc.
- iv) Residential facilities, e.g., houses, apartments etc.
- v) Cities, townships
- vi) Recreational facilities, e.g. parks. theatres etc.

According to the nature of layout problem, it can be categorised into four types as follows:

- Planning a completely new facility
- Expanding or relocating an existing facility
- Rearrangement of existing layout
- Minor modifications in present layout

Flow Patterns

According to the principle of flow, the layout plan arranges the work area for each operation, or process so as to have an overall smooth flow through the production/service facility. The basic types of flow patterns that are employed in designing the layouts are I-flow, L-flow, U-flow, O-flow, S-flow as shown in Figure 1. These are briefly explained below:

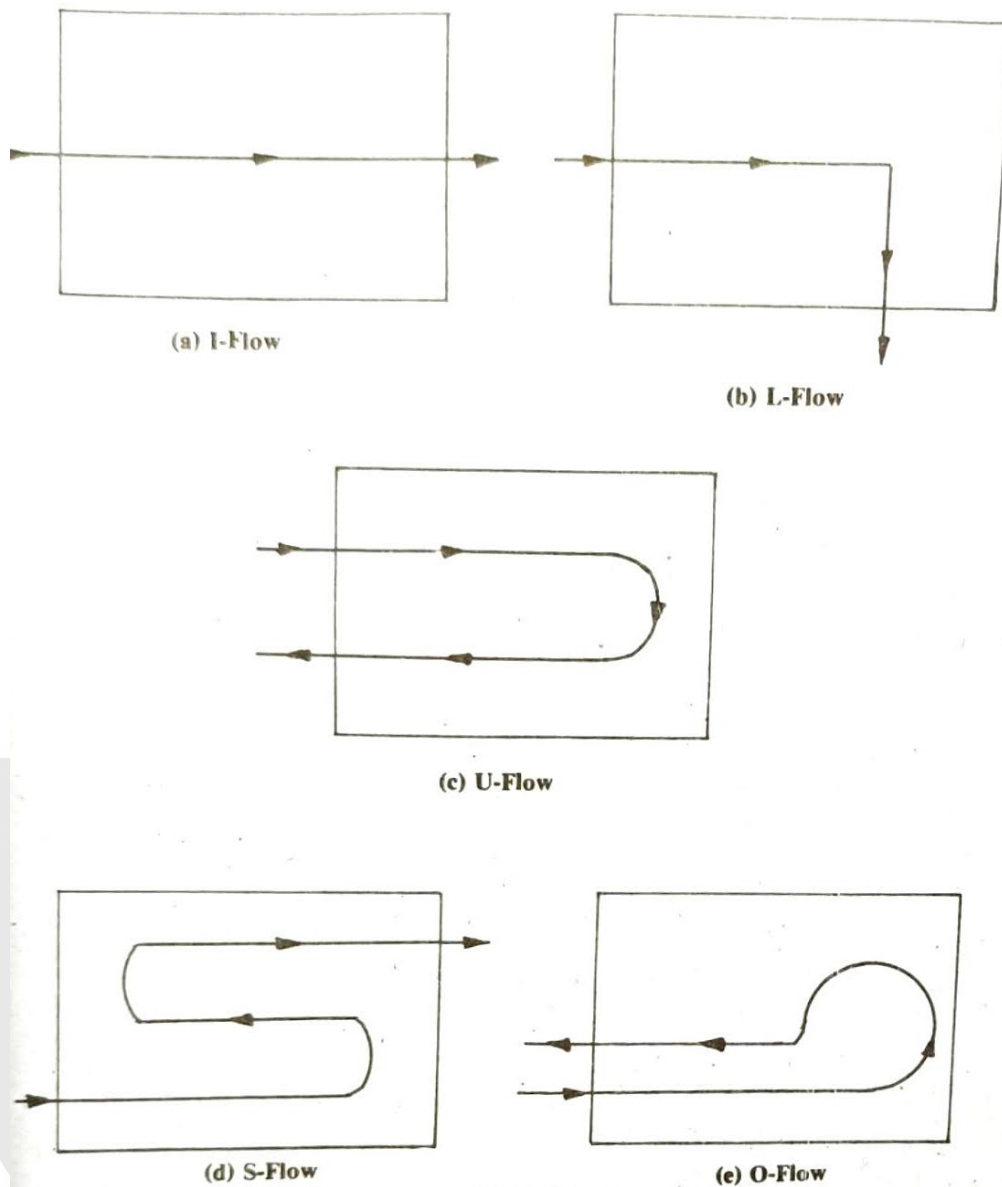


Figure 1 Flow Pattern

I- Flow: separate receiving and shipping area

L-Flow: when straight line flow chart to be accommodated.

U-Flow: very popular as a combination of receiving and shipping.

O-Flow: when it is desired to terminate the flow near where it is originated.

Serpentine or S-Flow: when the production line is long and zigzagging on the production floor is required.

4.2 BASIC TYPES OF PLANT LAYOUTS

Depending upon the focus of layout design there are five basic or classical types of layouts. Most of the practical layouts are a suitable combination of these basic types to match the requirements of activities and flow. The basic types of the layouts are:

A) Product or Line Layout (B) Process or functional Layout (C) Cellular or Group Layout (D) Project or Fixed Position Layout

A) Product or Line Layout

This type of layout is developed for product focused systems. In this type of layout only one product, or one type of product, is produced in a given area. In case of product being assembled, this type of layout is popularly known as an 'assembly line'

The work centres are organised in the sequence of operations. The raw material enters at one end of the line and goes from one operation to another rapidly with minimum of work-in-process storage and material handling. A typical product layout is shown in Figure II (a).

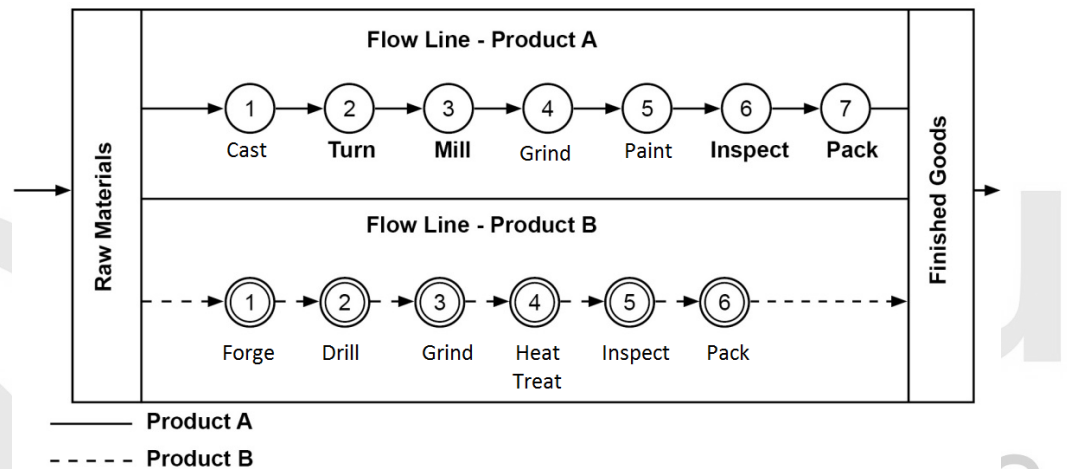


Fig II (a) Product or Line Layout

The decision to organise the facilities on a product or line basis is dependent upon a number of factors and has many consequences which should be carefully weighed. Following conditions favour the decision to go for a product focused layout.

- i) High volume of production for adequate equipment utilisation.
- ii) Standardisation of product and part interchangeability.
- iii) Reasonably stable product demand.
- iv) Uninterrupted supply of material.

The major problem in designing the product-focused systems is to decide the cycle time and the sub-division of work which is properly balanced (popularly known as line balancing).

Some of the major advantages of this type of layout are:

- i) Reduction in material handling.
- ii) Less work-in-process
- iii) Better utilisation and specialisation of labour

- iv) Reduced congestion and smooth flow
- v) Effective supervision and control.

(B) Process or Functional Layout

This type of layout is developed for process focused systems. The processing units are standardised by functions into departments on the assumption that. Certain skills and facilities are available in each department. Similar equipments and operations are grouped together, e.g., milling, foundry, drilling, plating, heat treatment etc. A typical process layout is shown in Figure II (b)

The use of process-focused systems is very wide both in manufacturing and other service facilities such as hospitals, large offices and municipal services etc.

The functional layout is more suited for low-volumes of production (batch production) and particularly when the product is not standardised. It is economical when flexibility is the basic system requirement. The flexibility may be in terms of the

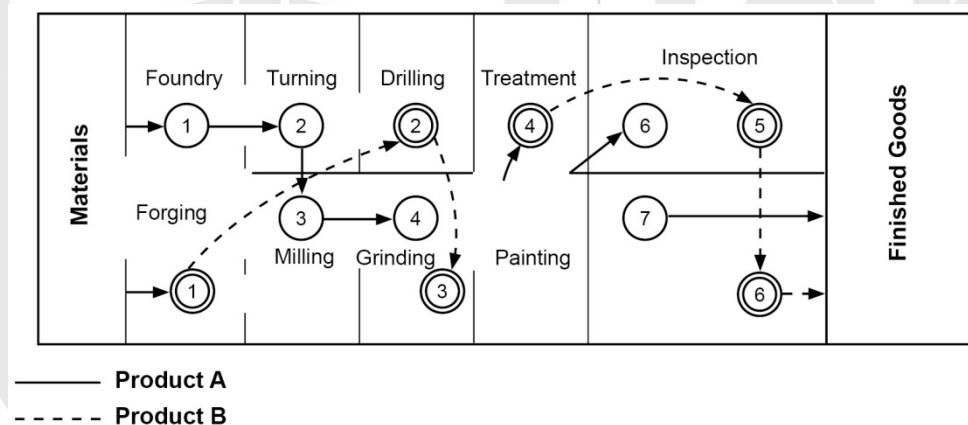


Fig II (b)- Process Layout

routes through the system, volume of each order, and the processing requirements of the 'items.

The major advantages of a process layout are:

- i) Better machine utilisation
- ii) Higher flexibility
- iii) Greater incentive to individual worker
- iv) More continuity of production in unforeseen conditions like breakdown, shortages, absenteeism etc.

(C) Cellular or Group Layout

It is a special type of functional layout in which the facilities are clubbed together into cells. This is suitable for systems designed to use the concepts, principles and approaches of group technology'. Such a layout offers the advantages of mass production with high degree of flexibility. We can employ

high degree of automation even if the number of products are more with flexible requirements. In such a system the facilities are grouped into cells which are able to perform similar type of functions for a group of products. A typical cellular layout is shown in Figure II (c).

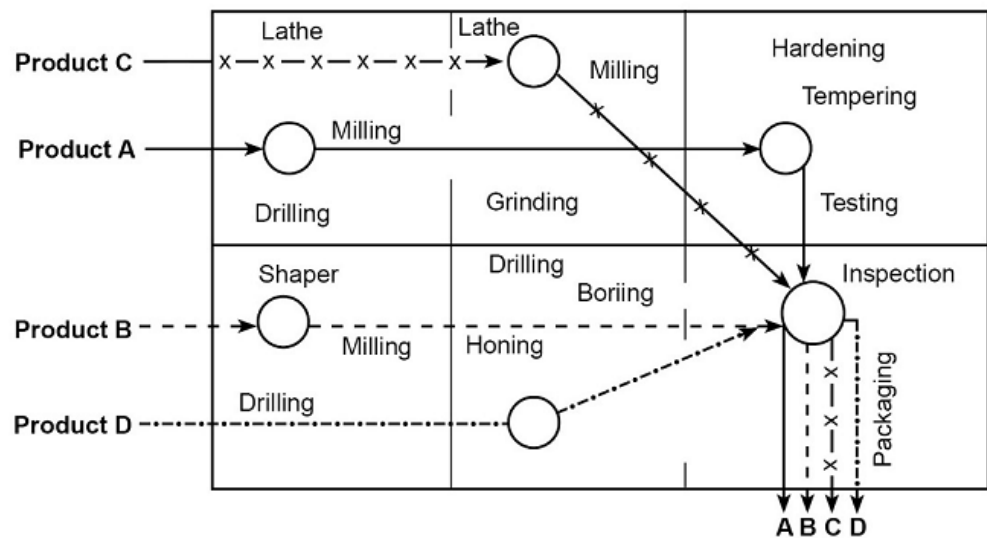


Fig : II (c) Cellular layout

Job-shop Layout

It is a layout for a very general flexible system that is processing job production. The preparation of such a layout is dependent on the analysis of the possible populations of orders and is a relatively, complex affair.

Project or Fixed Position Layout

This is the layout for project type systems in which the major component is kept at a fixed position and all other materials, components, tools, machines, and workers etc. are brought and assembly or fabrication is carried out. This type of layout is now not used very commonly as the machines required for manufacturing work are big and complicated. The fixed position layout is used only when it is difficult to move the big and major components and fabrication is to be carried out. A typical example is- production of ships.

Some of the major advantages of fixed position layout are as follows:

- i) The handling requirements for major unit are minimised.
- ii) Flexible with reference to the changes in product design.
- iii) High adaptability to the variety of product and intermittent demand.
- iv) The responsibility for quality can be pin-pointed.
- v) The capital investment is minimum.

A typical fixed position layout is shown in Figure II (d).

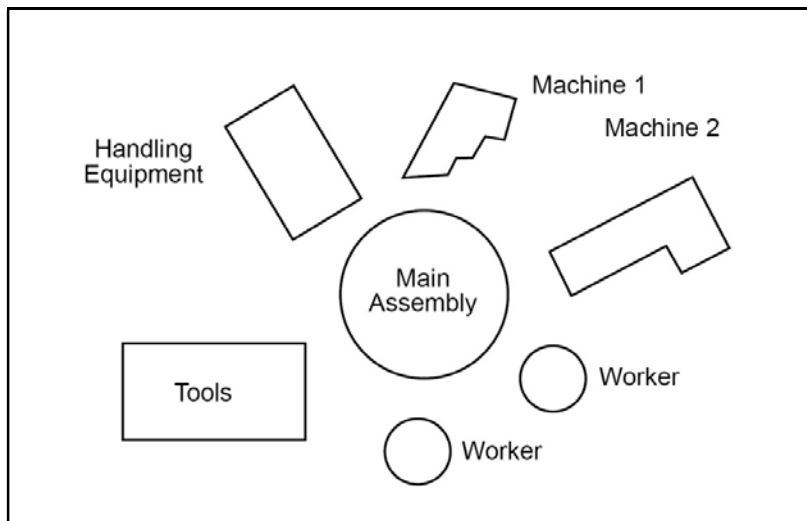


Figure II (d) Fixed position layout

The fixed position layout is used ideally for a project situation i.e. for one product of a different type. As the quantity increases the production operations can be broken down into different work centres and material can be allowed to move rather than the machines and a process layout is preferred. With further increase in volume i.e. with mass production the advantages of production line can be better derived and a product layout is desirable. The break-even analysis comprising the production volume of the three basic layouts i.e., product, process and fixed position layout is shown in Figure III.

Fig II: Breakeven point analysis of Basic types of Layout

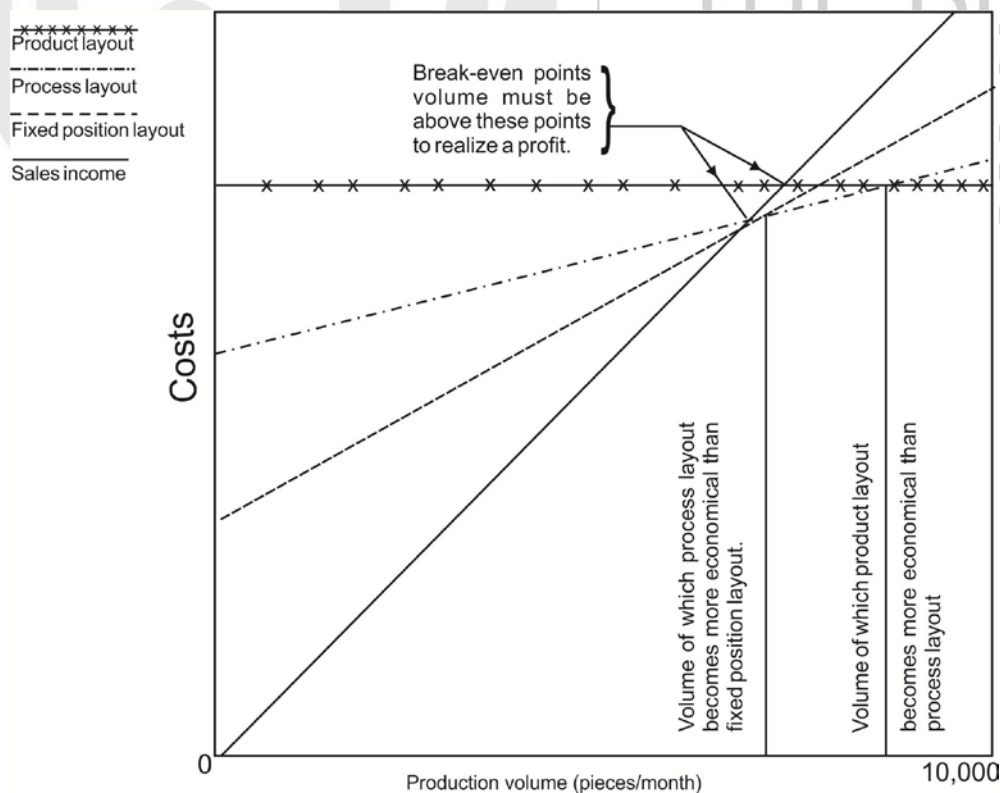


Fig. III Break-even Point Analysis of Basic Types of Layouts

4.3 PLANT LAYOUT FACTORS

The design of any layout is governed by a number of factors and the best layout is the one that optimises all the factors. As discussed by Muther (1955) the factors influencing any layout are categorised into the following eight groups:

- i) The material factor: Includes design, variety, quantity, the necessary operations, and their sequence.
- ii) The man factor: Includes direct workers, supervision and service help, safety and manpower utilisation.
- iii) The machinery factor: Includes the process, producing equipment and tools and their utilisation.
- iv) The movement factor: Includes inter and intradepartmental transport and handling at the various operations, storages and inspections, the materials handling equipments.
- v) The waiting factor: Includes permanent and temporary storages and delays and their locations.
- vi) The service factors: Include service relating to employee facilities such as parking lot, locker rooms, toilets and waiting rooms etc. service relating to materials in terms of quality, production control, scheduling, despatching, waste control; and service relating to machinery such as maintenance.
- vii) The building factor: Includes outside and inside building features and utility distribution and equipment.
- viii) The change factor: Includes versatility, flexibility and expansion.

Each of the above mentioned factors comprise a number of features and the layout engineer must review these in the light of his problem. Usually the layout design process is a compromise of these various considerations to meet the overall objectives in the best possible manner.

4.4 LAYOUT DESIGN PROCEDURE

The overall layout design procedure can be considered to be composed of four phases viz., Phase I Location

Phase II General Overall Layout

Phase III Detailed layout

Phase IV Installation

Some important guidelines that help in the layout design are:

- i) Plan from whole to details
- ii) First plan the ideal and then move to the practical aspects

- iii) Material requirements should be central to the planning of process and machinery.
- iv) Modify the process and machinery by different factors to plan the layout.

Though there is always an overlap in the different phases of layout design the major steps that have to be followed in the layout design are outlined as follows:

- i) Statement of the problem in terms of its objective, scope and factors to be considered.
- ii) Collection of basic data on sales forecasts, production volumes, production schedules, part lists, operations to be performed, work measurement, existing layouts and building drawings etc.
- iii) Analysis of data and its presentation in the form of various charts.
- iv) Designing the production process
- v) Planning the material flow pattern and developing the overall material handling plan.
- vi) Calculation of equipment requirements and work centres
- vii) Planning of individual work centres
- viii) Selection of material handling equipment
- ix) Determining storage requirements
- x) Designing activity relationships
- xi) Planning of auxiliary and service facilities
- xii) Calculation of space requirements and allocation of activity areas
- xiii) Development of Plot Plan
- xiv) Development of Block Plan
- xv) Development of detailed layouts in terms of steps (vii) to (xi)
- xvi) Evaluation, modification and checking of layouts
- xvii) Installation of layouts
- xviii) Follow up.

The S.L.P. (Systematic Layout Planning) procedure as presented by Francis and White (1974) is shown in Figure IV. We see that once the appropriate information is gathered, a flow analysis can be combined with an activity analysis to develop the relationship diagram. Space considerations when combined with the relationship diagram lead to the construction of the space relationship diagram. Based on the space relationship diagram, modifying considerations and practical limitations, a number of alternative layouts are designed and evaluated.

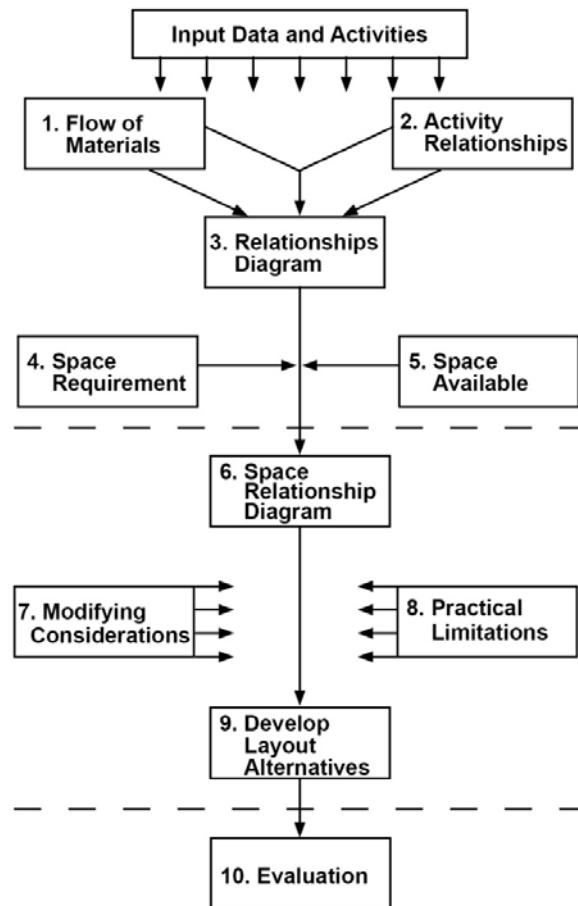


Fig IV- Systematic Layout Planning Procedure

4.5 FLOW AND ACTIVITY ANALYSIS

Data Collection

The development of any layout is dependent on the quality and quantity of facts that we have about the various factors influencing it. The data collection phase is not a one time effort but an ongoing function. The data for overall plan is to be collected at initial stages whereas the data for detailed layouts may be obtained at a later stage.

The facts have to be obtained regarding various materials and processes, the flow routing and sequencing, space requirements, and different activities and relationships. The information required about the materials and processes is listed in Table 1. We will now discuss some of the tools and techniques that help in the layout analysis..

Table 1
Information Required about Materials and Processes

	Data Required	Source of Data
Product Specifications	Product size, weight and shape Quality requirements Special properties	Product engineering, quality control inspection
Production Volume	Number of different items (product mix) Quantity of each item per unit time Variation in output Variation in demand	Sales department, market research, production planning
Component Parts	Performance times for all operations Variation in performance times Sequence of fabrication Operations Sequence of assembly Operations Types of machinery required	Production Planning, time study department

Source: Moore, J.M. 1970. *Plant Layout and Design*. The Macmillan Company: New York.

Process Charts

There are many types of process charts that can be developed. The most commonly used ones are operation process charts and Flow Process Charts. ,

Operation Process Chart: This is a graphic representation that describes the different operations (O) and inspection (□) in a sequential manner including information regarding time and location etc.

xix) **Flow Process Chart:** The arrangement of facilities in a production process govern the flow of product and vice-versa. Thus the analysis of flow should be carried out closely when formulating a plant layout proposal. The flow process chart summarises the flow and activity of a component/man through a process or procedure in terms of sequence of operation, transportation, inspection, delay and storage. It includes the information about time required and distance moved. A sample flow process chart is shown in Figure V.

Flow -Diagram

It is a sketch of the layout which shows the location of all activities appearing on a flow process chart. The path of movement of material or man is traced on the flow diagram. The different activities are given by process chart symbols with a number. This gives an idea about the overall flow through the plant in a pictorial manner.

Any back tracking or crisis crossing of the flow can be pin-pointed and the layout engineer can redesign the layout for a smoother flow by minimising these wasteful flows. If necessary a three dimensional flow diagram can be developed, particularly in case of multi-storeyed buildings. This helps in the activity relationship diagram which when superimposed by space relationship results in block plan.

Travel Chart

It is also known as **From-To Chart**.

This chart is helpful in analysing the overall material flow. It indicates the distance and number of moves between different pairs of departments taken as origin and destination. The travel chart is helpful in the process type layout design; but in product layout, it is not important. It indicates the relationship between different departments in terms of material interaction. Attempts should be made in layout design to put those departments close to each other which have high level of material interaction so as to minimise the materials handling requirements provided other objectives are also satisfied. In most of the practical situations, it may be difficult to achieve the theoretical optimum, but the closest possible solution to the optimum. should be approached.

Analysis					Question each detail	FLOW PROCESS CHART				No. <u>1</u>							
What?	Where?	When?	Who?	How?						Page/ of <u>1</u>							
					Summary				Job <u>Cast, Turn & Drill</u>								
					Present		Proposed		Difference		☐ Man or ☒ Material						
					No	Time	No	Time	No	Time	Chart begins <u>Raw material store</u>						
☐ Operations					3	90					Chart ends <u>Inspection</u>						
☒ Transportations					2						Charted by <u>Sushil</u>						
☐ Inspections					1	10					Date <u>20-3-87</u>						
☐ Delays					2	35											
☐ Storages					3												
Distance traveled					15 m												
Details of (present) method proposed					Possibilities								Notes				
					Operation	Transport	Inspection	Delay	Storage	Distance in m	Quantity	Time (min.)		Eliminate	Combine	Sequence	Place
1.	Raw material store	☐	☒	☐	☐												
2.	Casting	☒	☐	☐	☐			60								X	
3.	Casting store	☐	☒	☐	☐												
4.	Handling to turning shop	☐	☒	☐	☐	10						X					
5.	Delay at Lathe M/C	☐	☒	☐	☐		10	20									
6.	Turning	☒	☐	☐	☐			15									
7.	Work in process store	☐	☒	☐	☐												
8.	Handling to drilling shop	☐	☒	☐	☐	5											
9.	Delay at Drilling M/C	☐	☒	☐	☐		8	15	X								
10.	Drilling	☒	☐	☐	☐			15								X	
11.	Inspection	☐	☒	☐	☐			10									
12.		☐	☒	☐	☐												
13.		☐	☒	☐	☐												
14.		☐	☒	☐	☐												

Figure V: Flow Process Chart Summaries The Flow and All Activity of A Component Through its Manufacturing Process

The travel chart summarises the data on material handling in compact matrix form, which is amenable to computer applications also. Further, the information

regarding the bulk of material handled, mode of material handling and material handling equipment etc. may also be listed to make it more informative.

The following example will explain the travel chart.[Fig VI(a to d)]

Existing plant layout showing the locations of various departments (A to F) is given in the Fig VI (a)

A	B	C
D	E	F

Fig VI (a) First step: (Existing Layout)

2nd Step : Movements from A to B are 20, B to A 10, B to C 15, A to F 25, C to D 30, D to C 50, D to F 40, E to F 10 and F to E 15

3rd Step : A square Grid is drawn and the various movements are marked Fig VI (b)

4th Step : Fig VI(c) is simplified by combining movements like A to B (20) and B to A (10) which involve same distance and ,therefore, total movement.

$$B \rightleftharpoons A = 20 + 10 = 30$$

From \ To	A	B	C	D	E	F
A		10				
B	20					
C		15		50		
D			30			
E						15
F	25			40	10	

Fig. vi(b)

From \ To	A	B	C	D	E
A					
B	30				
C		15			
D			80		
E					
F	25			40	25

Fig. VI(c)

This Simplified Travel Chart (see Fig VI (c)) shows the movement as follows

$$\begin{aligned} A \rightleftharpoons B &= 30 \\ B \rightleftharpoons C &= 15 \\ C \rightleftharpoons D &= 80 \\ A \rightleftharpoons F &= 25 \\ D \rightleftharpoons F &= 40 \\ E \rightleftharpoons F &= 25 \end{aligned}$$

According to these figures maximum number of movements are between departments C and D, Hence in the plant layout these two departments should be side by side. The next lesser number of movements are between D and F, hence D and F should also lie closer to each other and so on. As a result the existing plant layout can be modified as shown in Figure VI (d)

C	D	A
E	F	B

Fig VI(d) Modified Layout

Departement C and D (80), D and F (40), A and B (30), A and F (25), E and F (25) are closure to each other whereas B and C which have minimum number of movements (i.e 15) between them, are away from each other

Some of the important advantages and uses of travel chart are:

- It helps in analysing the material movement
- It aids in determining activity locations
- It alternates flow patterns and layouts can be compared
- It shows relationship of different activities in terms of volume of movement.
- It depicts quantitative relationships which can be used for computerised analysis and OR applications.

REL CHART. This is known as ‘Relationship Chart’ which indicates the relationship between pairs of departments in terms of closeness depending upon the activities of the departments as A-Absolutely essential, E-Essential, I-Important, O-Ordinary, U-Unimportant and X-Undesirable. A typical Rel Chart is shown in Fig VII.

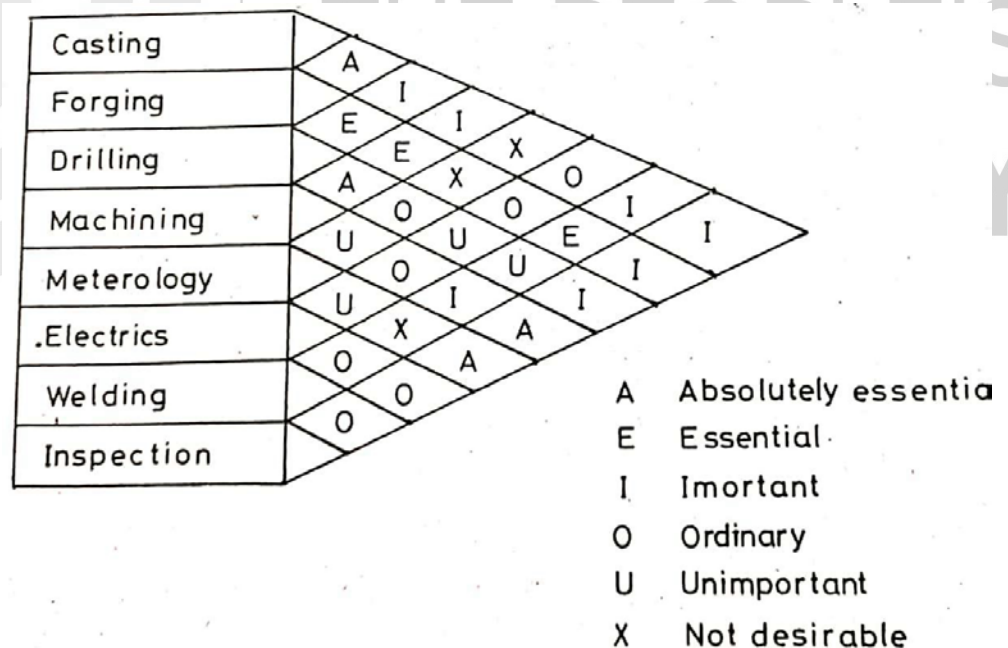
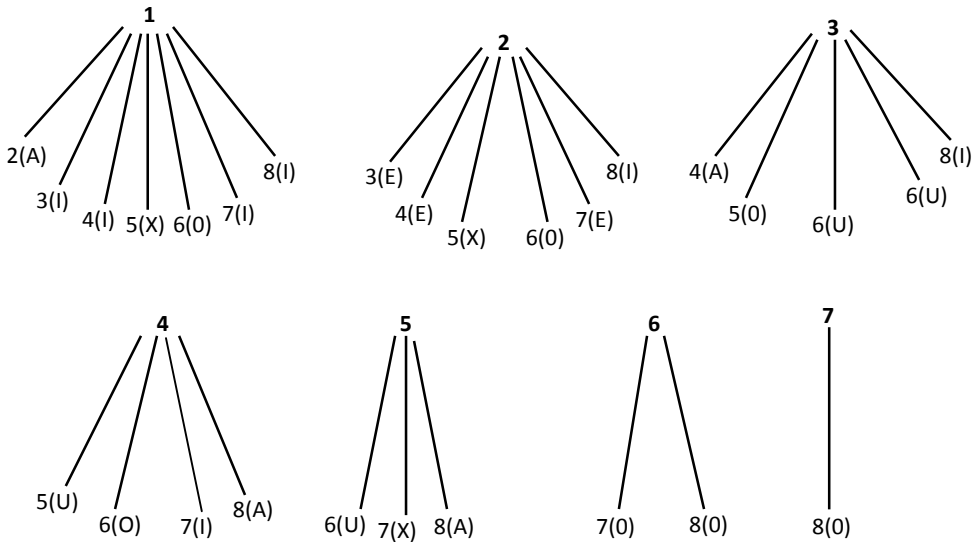
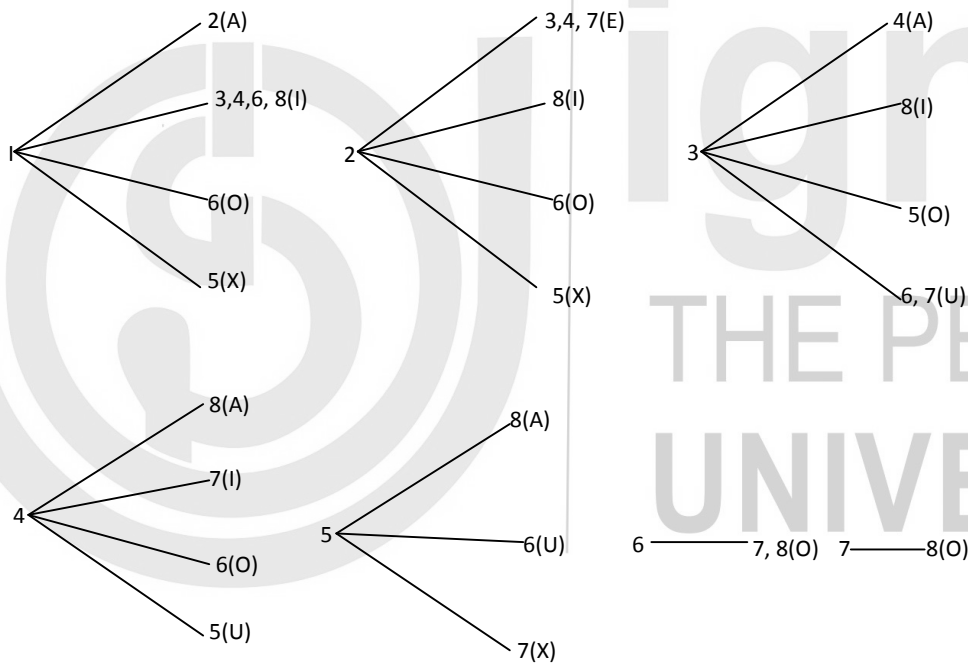


Fig VII: REL Chart

For the given nearness diagram expressing the proximity requirements, we can attempt to arrange the work centres into a suitable 2×4 or 4×2 grid. Shown below is the method of construction of the proximity grid (The method is self-explanatory).



Step 1. Show the various work centres with their nearness with respect to other work centres in an exploded form as shown above.



Step 2. Next show the nearness of other centres with their attributes of proximity (A, E, I, O, U, X) with respect to work stations 1, 2, 3, 4, 5, 6, 7, 8 as shown above.

1	2	7	6
3	4	8	5

Or

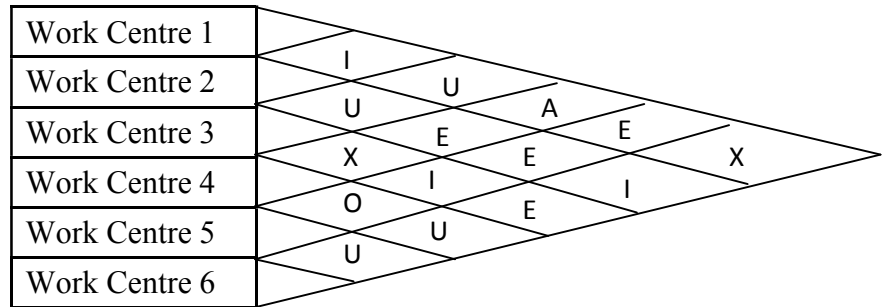
1	3
2	4
7	8
6	5

Arrangement of work centres in 2 x 4 or 4 x 2 grid.

Step 3: Finally arrange the various work centres in the proximity grid of 2×4 or 4×2 as shown above

Example 4.1: Given the following nearness diagram expressing the proximity requirements.

Arrange the work centres into a suitable 2×3 or 3×2 grid. The symbols A, E, I, O, U, X have their usual meaning.



Solution

2	1	3
5	4	6

2×3 grid

or

2	5
1	4
3	6

3×2 grid

Application of Quantitative Techniques

The techniques of Operations Research can be applied to quantitatively analyse the layout problems, particularly, in terms of material flow. Some of the important techniques that have been applied by different researchers in the field of layout planning are as follows:

- i) Linear Programming
- ii) Transportation Algorithm
- iii) Transshipment Problem
- iv) Assignment Problem
- v) Travelling Salesman Problem
- vi) Dynamic Programming
- vii) Queueing Theory
- viii) Simulation.

Linear Programming is used when there is a linear objective function which is to be maximised/minimised subject to certain linear constraints. In the layout design the objective is to minimise the Materials handling. Transportation and assignment problems are special cases of Linear Programming. Further, to meet the multiple objectives of layout planning attempts have also been made to apply **Goal Programming** as a technique of Multi-criteria Decision-making. These operations research techniques are discussed in other course.

4.6 SPACE DETERMINATION AND 'AREA ALLOCATION

In the layout planning process the space is allocated to different activities. The requirement of space by a facility bears a close relationship to equipment, material, personnel and activities. Two major methods that are being used for space calculations are space based on present layout and production centre method.

Space Based on Present Layout

This approach is suitable when the proposed layout is to be developed for an existing product. While determining the space, consideration should be given to space required for the following:

- operating equipment
- storage
- service facilities,
- operators

Allowance must be made for space between machines for operator movement, work in-process, access of materials handlers and maintenance personnel etc.

Production Centre Method

The space for each production centre is determined including the space for machines, tool cabinets, worked and unworked parts, access to the aisle and maintenance. In this method actual arrangement of equipment is considered for space calculation. The departmental space is calculated by multiplying it with the number of production centres in that department.

Work Place Layout

The details of the arrangements at a work centre is to be provided in terms of the machines and auxiliary equipment, operator, tools, materials and auxiliary services. The procedure for work place design is as follows:

- i) Determination of direction of overall flow
- ii) Determination of the desired direction of flow at work place
- iii) Determination of the items contained in a work place
- iv) Sketching the arrangement of these items
- v) Specifying the sources of material and direction of flow
- vi) Indicating the destination of material
- vii) Method of waste disposal specified
- viii) Sketching the material handling equipment
- ix) Checking the arrangements against the principles of motion economy
- x) Marking of distances between items

- xi) Recording the layout on scale
- xii) Indicate method of operation on chart,

Area Allocation

The activity relationships and space requirements are integrated to allocate the areas which forms the basis for detailed layout planning. There are a number of factors that should be considered for area allocation, some important ones are:

- i) Area should be allocated for expansion purposes. The allocation of expansion area depends upon the type of flow pattern i.e. straight line, U-flow and 0-flow etc.
- ii) Area allocation to maintain flexibility in layout.
- iii) Maximum use of third dimension
- iv) Area allocation for point of use storage and centralised storage
- v) Area allocation for aisles
- vi) Consideration of column spacing.

4.7 COMPUTERISED LAYOUT PLANNING

A recent trend has been the development of computer programme to assist the layout planner in generating alternative layout designs. Computerised layout planning can improve the search of the layout design process by quickly generating a large number of alternative layouts.

Computer programmes are generally either construction programmes or improvement programmes:

i) Construction programmes (Successive selection and placement of activities)	CORELAP (Computerised Relationship Layout Planning) ALDEP (Automated Layout Design Programme)
ii) Improvements programmes	CRAFT (Computerised Relative Allocation of Facilities Techniques)

A complete existing layout is required initially and locations of department are inter-changed to improve the layout design.

Both ALDEP and CORELAP are concerned with the construction of a layout based on the closeness ratings given by the REL chart.

CRAFT is concerned with the minimisation of a linear function of the movement between departments. Typically CRAFT employs an improvement procedure to obtain a layout design based on the objective of minimising material handling costs.

CORELAP (computerised Relationship layout Planning)

It begins by calculating which of the activities in the layout is the busiest or most related. The sums of each activity's closeness relationships with all other activities are compared and the activity with the highest total closeness relationship (TCR) count is selected and located first in the layout matrix. This activity is named **Winner**. Next, an activity which must be close to the winner is selected and placed as adjacent as possible to winner. This activity is denoted as A (closeness absolutely necessary) and is named **Victor**. A search of winner's remaining relationships for more A-related victors is then made. These are placed, again, as close to each other as possible. If no more A's can be found, the victors become potential winners and their relationships are searched for A's. If an A is found, the victor becomes the new winner, and the procedure is repeated. When no A's are found, the same procedure is repeated for E's (closeness Especially important), I's (closeness important), and O's (Ordinary closeness o.k.) until all activities have been placed in the layout. CORELAP also puts a value on the U (closeness Unimportant) and X (closeness not desirable) relationship.

ALDEP (Automated layout Design Programme)

It uses a preference table of relationship values in matrix form to calculate the scores of a series of randomly generated layouts. If for example, activities 11 and 19 are adjacent, the value of the relationship between the two would be added to that layout's score. A modified random selection technique is used to generate alternate layouts. The first activity is selected and located at random. Next, the relationship data are searched to find an activity with a high relationship to the first activity. This activity is placed adjacent to the first. If none is found, a second activity is selected at random and placed next to the first. This procedure is continued until all activities are placed. The entire procedure is repeated to generate another layout. The analyst specifies the number of layouts wanted which must satisfy a minimum score.

CRAFT (computerised Relative Allocation of Facilities Techniques)

It is the only one which uses flow of materials data as the sole basis for development of closeness relationships. Material flow, in terms of some unit of measurement (pounds per day, in terms of skid-loads per week), between each pair of activity areas, forms the matrix to the programme.

A second set of input data allows the user to enter cost of moving in terms of cost per unit moved per unit distance. In many cases this cost input is unavailable or inadequate, in which case it can be neutralised by entering 1.0 for all costs in the matrix.

Space requirements are the third set of input data for CRAFT. These take the form of an initial or an existing layout. For new area layouts, best guess or even completely random layouts can be used. In any case, activity identification numbers, in a quantity approximate to their space requirements, are entered in

an overall area of close proximity. The location of any activity can be fixed in the overall area through control cards. CRAFT limits the number of activities involved in the layout to 40.

4.8 EVALUATION, SPECIFICATION, PRESENTATION AND IMPLEMENTATION

Plot Plan

It is a diagrammatic representation of the building outline, showing its location on the property, the location of external transportation facilities and other items such as tanks, storage areas and parking lots etc. It can be used as a key or master drawing for locating separate detailed drawings of the layout. The plot plan is presented in the form of a drawing or as a scaled model.

Block Plan

A block plan is a diagrammatic representation showing internal partitions of departments, columns and area allocation but not machinery, equipment and facilities. This is usually presented in the form of drawings and is used as a reference or master for detailed layouts of different departments. This shows the area allocations for aisles and column spacing etc.

Detailed Layout

It is a diagrammatic representation of the arrangement of equipment operator and materials along with the arrangement of supporting activities. The detailed layout can be constructed by utilising any one of the following methods

- drafting or sketching
- templates
- models

A **template** is a scaled representation of a physical object in a layout may be of a machine, workman, material handling equipment, work-in-process and storage etc.

Models are three dimensional representations of the physical objects which give depth to the layout and make it more presentable.

These templates and models may be prepared from cardboard, paper, sheet metal, plastic or wood and may be black and white or coloured. These may be attached to the backing material by using various fastening devices such as glue, staples, rubber cement, thumbtacks and magnetism etc.

Checking the Layout

The layout finally developed should be checked for

- overall integration
- minimum distance moved
- smooth flow of the product

- space utilisation
- employee satisfaction and safety
- flexibility

The flexibility should be introduced in building and services by providing unobstructed floor area and in equipment by mounting them on wheels or skids.

Evaluation of Layout

The evaluation may be done of an existing layout or of an alternative layout. The basis for evaluating the layout might include:

- i) the objectives of layout planning
- ii) cost comparison with other alternatives
- iii) return on investment
- iv) intangible factors which must be evaluated on the basis of judgment.
- v) productivity evaluation
- vi) space evaluation
- vii) ranking
- viii) pilot plant
- ix) sequence demand-straight line-considering the sequence of operations on a variety of parts.
- x) Factors analysis by weighing various factors according to their importance.

The optimising evaluation can also be done by using Operations Research Techniques such as

- Linear Programming
- Line Balancing
- Level Curve Concept

Mathematical models express the effectiveness of layout as a function of a set of variables which can be evaluated. Some other mathematical techniques of evaluation are:

- Monte Carlo Method
- Queuing Theory
- Engineering Economy
- Analogues

These are not discussed in details here.

Installation of Layout

The layout is presented in the following ways:

- i) The Visual presentation of the layout itself, supplementary details and facts and supplementary charts and displays.
- ii) An Oral report
- iii) A Written report

When the final layout is approved it is installed in a number of phase, and it is needed to prepare

- detailed drawings
- precise specifications of production and materials handling equipment
- detailed listing of all equipment and utility requirements
- actual plans and schedule of construction and installation.

The techniques of project management such as CPM/PERT may be used for planning and monitoring the progress of the layout installation.

4.9 MATERIALS HANDLING SYSTEMS

We have discussed in previous sections the analysis of material flow and the design of layout based on it. We have referred to the selection of material handling equipment and area allocation for it. Materials handling is the art and science involving the movement, packaging and storing of substances in any form. **Material Handling is a system which forms the various factors of movement, transfer, warehousing, in-process handling and shipping into one independent cycle considering the most economical solution for the respective plant.** In this section we will discuss about the objectives of the material handling system design, basic types of material handling systems and the procedure for the design and selection of material handling system while developing a plant layout.

Objectives and Functions

In order to perform the activities of materials handling the basic goal is to minimise the production costs. This general objective can be further subdivided into specific objectives as follows:

- i) To reduce the costs by decreasing inventories, minimising the distance to be handled and increasing productivity.
- ii) To increase the production capacity by smoothing the work flow.
- iii) To minimise the waste during handling
- iv) To improve distribution through better location of facilities and improved routing.
- v) To increase the equipment and space utilisation.
- vi) To improve the working conditions.
- vii) To improve the customer service.

The analysis of materials handling requirements can be carried out by using travel charts and other quantitative techniques as outlined in section 4.5.

The basic materials handling function has to answer a number of questions as follows:

- i) Why do this at all? Justifying the necessity of material handling.
- ii) What material is to be handled? Giving the type (unit, bulk etc.), characteristics (shape, dimension etc.) and quantity.
- iii) Where and when? Specifying the move in terms of source and destination, logistics, characteristics (distance, frequency, speed and sequence etc.) and type (transporting, conveying and positioning etc.)
- iv) How? And Who? Specifying the method in terms of the handling unit (load support, container, weight, number etc.), equipment, manpower, and physical restrictions (column spacing, aisle width and congestion etc.)

Basic Materials Handling Systems

The different material handling systems can be classified according to the type of equipment used, material handled, method used or the function performed.

Equipment-Oriented Systems: Depending upon the type of equipment used, there are several systems.

- i) Overhead systems
- ii) Conveyor systems
- iii) Tractor-trailor system
- iv) Fork-lift truck and pallet system
- v) Industrial truck systems
- vi) Underground systems.

Material Oriented Systems: These may be of the following types.

- i) Unit handling systems
- ii) Bulk handling systems
- iii) Liquid handling systems

A unit load consists of a number of items so arranged that it can be picked up and moved as a single entity such as a box, bale, roll etc. Such a system is more flexible and requires less investment.

Method Oriented Systems: According to the method of handling and method of production, the material handling systems can be:

- i) manual systems
- ii) mechanised or automated systems
- iii) job-shop handling systems, or

iv) mass-production handling systems

Function Oriented Systems: The systems can be defined according to the material handling function performed as follows:

- i) Transportation systems
- ii) Conveying systems
- iii) Transferring systems
- iv) Elevating systems

Selection and Design of Handling System

The selection and design of the material handling system should be done alongside the development of the layout as each one affects each other. Hence, an integrated approach to the design process is usable. A computerised technique known as COFAD (Computerised Facilities Design) has been developed for integrated handling system and layout design. The steps to be followed in the selection and design of handling systems are as follows:

- i) Identification of system
- ii) Review of design criteria and objectives of the handling system
- iii) Data collection regarding flow pattern and flow requirements
- iv) Identification of activity relationships
- v) Determining space requirement and establishing material flow pattern
- vi) Analysis of material and building characteristics
- vii) Preliminary selection of basic handling system and generation of alternatives considering feasibility of mechanisation and equipment capabilities
- viii) Evaluation of alternatives with respect to optimal material flow, utilising gravity, minimum cost, flexibility, ease of maintenance, capacity utilisation and other objectives of the system design considering various tangible and intangible factors
- ix) Selection of the best suited alternative and checking it for compatibility
- x) Specification of the system
- xi) Procurement of the equipment and implementation of the system

4.10 MATERIALS HANDLING EQUIPMENT

After the simplification of the handling method the selection of equipment is important with respect to the different objectives of speed, efficiency-cost etc. There are both the manual and powered kind of handling equipments. Some of the typical handling equipments are shown in Figure VIII. Apple (1982) (Apple James M-plant Layout and Material Handling- New York. James

Wiley and Sons-1982) has classified the handling equipments into four basic types, viz., conveyers, cranes and hoists, trucks, and auxiliary equipment.

Conveyers

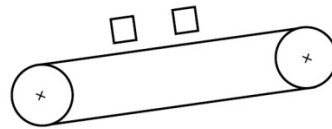
These are gravity or powered devices commonly used for moving uniform loads from point to point over fixed paths, where the primary function is conveying. Commonly used equipment under this category are:

- i) Belt Conveyer
- ii) Roller Conveyer
- iii) Chain Conveyer
- iv) Bucket Conveyer
- v) Trolley Conveyer
- vi) Screw Conveyer
- vii) Pipeline Conveyer
- viii) Vibratory Conveyer
- ix) Chute.

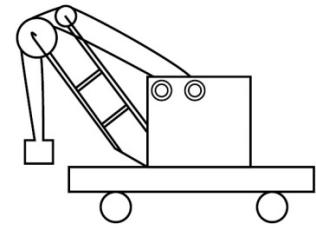
Cranes, Elevators and Hoists

These are overhead devices used for moving varying loads intermittently between points within an area, fixed by the supporting and binding rails, where the primary function is transferring or elevating. Some common examples are:

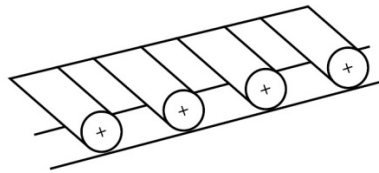
- i) Overhead travelling crane
- ii) Gantry crane
- iii) Jib crane
- iv) Elevators
- v) Hoists
- vi) Stacker crane
- vii) Winches
- viii) Monorail



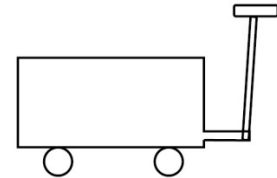
(a) Bell conveyer



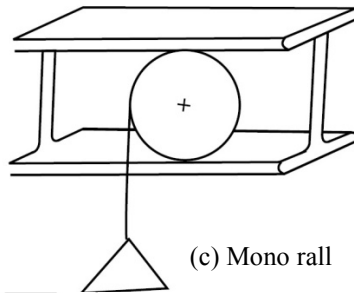
(d) Mobile crane



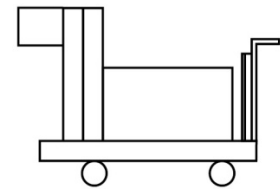
(b) Roller conveyor



(e) Hand trolley



(c) Mono rall



(f) Fork lift truck

Fig. VIII: Material Handling Equipment

Industrial Trucks and Vehicles

These are hand operated or powered vehicles used for movement of uniform or mixed loads intermittently over various paths having suitable running surfaces and clearances where the primary function is manoeuvring or transporting. These include:

- i) Fork lift truck
- ii) Platform truck
- iii) Industrial tractors and trailers
- iv) Industrial cars
- v) Walkie truck
- vi) Two-wheeled hand truck or trolley
- vii) Hand stacker

Auxiliary Equipment

These are devices or attachments used with handling equipment to make their use more effective and versatile. Some common examples are:

- i) Ramps
- ii) Positioners
- iii) Pallets and skids
- iv) Pallet loader and unloader
- v) Lift truck attachments
- vi) Dock boards and levelers
- vii) Containers
- viii) Below the hook devices
- ix) Weighing equipment

4.11 SUMMARY

In this unit we have discussed different types of layout problems. The basic types of plant layouts have been identified as product layout, process layout, job shop layout, cellular layout and fixed position layout. The factors to be considered in designing plant layout are outlined as man, material, machine, movement or flow, service facilities, building and flexibility.

The tools and techniques for analysing the flow of materials and the activities have been discussed. Some important tools are, flow process chart, flow diagram, travel chart, REL chart etc. By making use of these tools a systematic layout planning procedure has been discussed starting from the development of plot plan to detailed work place layout. The use of computers in layout planning has been highlighted and computerised techniques named as CORELAP, ALDEP and CRAFT have been outlined. The art of presentation and implementation of the layout has been briefly dealt with. The selection of materials handling system has been presented along with the important types of materials handling equipments. The important concepts in automation in layout and materials handling have been touched upon.

4.12 KEY WORDS

ALDEP: Automated Layout Design Programme

Block Plan: A diagrammatic representation showing internal partitions of departments, columns and area allocation but not machinery, equipment or facilities.

CORELAP: Computerised Relationship Layout Planning

CRAFT: Computerised Relative Allocation of Facilities Technique.

Facility: Any production, operation or service unit is termed as facility, e.g. plant, stores, bank, hospital, machine, equipment and service centre etc.

Flow Diagram: A sketch of the layout which shows the location of all activities appearing on a flow process chart.

Flow Process Chart: It summarises the flow and activity of a component/man through a process or procedure in terms of sequence of operation, transportation, inspection, delay and storage.

Materials Handling: It is the art and science involving the movement, packaging and storing of substances in any form.

Plant Layout: A plan or the act of planning, an optimum arrangement of industrial facilities including operating equipment, personnel, storage space, materials handling equipment and all other supporting services, along with the design of the best structure to contain these facilities.

Plot Plan: A diagrammatic representation of the building outline, showing its location on the property, the location of external transportation facilities and other items such as tanks, storage areas and parking lots etc.

Process Layout: Also known as functional layout groups together the facilities according to process or function in a department.

Product Layout: Also known as line layout is an arrangement of facilities according to the product; suitable for one type of product.

REL Chart: It indicates the relationship between pairs of departments in terms of closeness rating dependent upon the activities of the department as absolutely essential, essential, important, ordinary, unimportant or not desirable.

SLP: Systematic Layout Planning.

Template: A scaled representation of a physical object in a layout may be of a machine, workman, materials handling equipment, work in process, and storage etc.

Travel Chart: It indicates the distance and number of moves between different departments, taken as origin and destination.

4.13 SELF-ASSESSMENT EXERCISES

- 1) Enumerate the basic types of plant layouts. How does a cellular layout differ from a process layout?
- 2) What are the different factors that should be considered for designing a plant layout?
- 3) Prepare a flow chart for overhauling the engine of an automobile.

- 4) What is the significance of travel charts in layout design? Prepare a travel chart for a hypothetical engineering concern with five functional departments, i.e foundry, forging, machining, welding and inspection (you may assume your own data). Given this travel chart proceed to find the locations of different departments.
- 5) How can the relationships of different departments be considered in preparing a layout? Prepare a REL chart for the different departments of a typical hospital.
- 6) What is Systematic Layout Planning?
- 7) What are the different factors that you will consider in determining the space requirement of a particular facility? Allocate the areas to different departments considered in exercise 4 and develop a blockplan.
- 8) Outline the basic logic used in CORELAP, ALDEP and CRAFT. Can the layout generated by these computerised techniques be directly implemented?
- 9) How will you specify and present a layout developed for the purposes of implementation?
- 10) What is the importance of materials handling in designing a layout? How will you go about selecting the materials handling system?
- 11) What are the different kinds of materials handling equipments used? is a totally automated materials handling system desirable in a job shop?

4.14 FURTHER READINGS

Adam Jr E.E and R.J.Ebert,. Production and Operations Management
Prentice- Hall Inc.:Englewood-Cliffs

Ballou,R.H. Business Logistics Management, Prentice-Hall Inc.:Englewood-Cliffs.

Buffa,E.S. Operations Management: The Management Of Productive Systems,John Wiley:New York

Chase R.B and N.J Aquilano. Production in operations Management. Richard D Edwin:Homewood.

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BLOCK-2

OPERATION PLANNING AND CONTROL

UNIT 5 Planning and Control for Mass Production

UNIT 6 Planning and Control for Batch Production

UNIT 7 Planning and Control for Job Shop Production

UNIT 8 Planning and Control of Projects

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BLOCK 2 OPERATION PLANNING AND CONTROL

The four units of this block deal with the problems of production/operations management in different kinds of production systems. These systems are based on material flow characteristics I, e. Mass Production (Unit 5), batch Production (Unit 6), Job Shop Production (Unit 7) and finally planning and control of Unit manufacture of projects (Unit 8), Optimal layout, aggregate production planning, machine — Job allocations, determination of Economic batch Quantity (Unit 6), Priority dispatching rules (Unit 7) and Project Planning and Monitoring Techniques based on Network Models for projects (Unit 8) have been discussed with their salient features.



UNIT 5 PLANNING AND CONTROL FOR MASS PRODUCTION

Objectives

After completion of this unit, you should be able to:

- understand the nature of mass / flow production, identify the situations under which mass production is justified and appreciate both the desirable and undesirable features of mass production
- see how assembly lines and fabrication lines are designed, get an idea of how modular production and group technology could be used to advantage in mass production and understand the role of automation including robotics in mass production.

Structure

- 5.1 Introduction
- 5.2 When to Go For Mass Production
- 5.3 Features of a Mass Production System
- 5.4 Notion of Assembly Lines and Fabrication Lines
- 5.5 Design of an Assembly Line
- 5.6 Line Balancing Methods
- 5.7 Problems and Prospects of Mass Production
- 5.8 Modular Production and Group Technology
- 5.9 Automation and Robotics
- 5.10 Summary
- 5.11 Key Words
- 5.12 Self-assessment Exercises
- 5.13 Further Readings

5.1 INTRODUCTION

Kinds of Production Systems: flow Shops, Job Shops and Projects

As you already know, production involves the transformation of inputs (such as men, machines, materials, money, information and energy) to desirable outputs in the form of goods and services. It is customary to divide production systems into three categories: the flow shop, the job shop and the project. The flow shop exists when the same set of operations is performed in sequence repetitively; the job shop exists where the facilities are capable of producing many different jobs in small batches; the project is a major undertaking that is usually done only once. It consists of many steps that must be sequenced and coordinated.

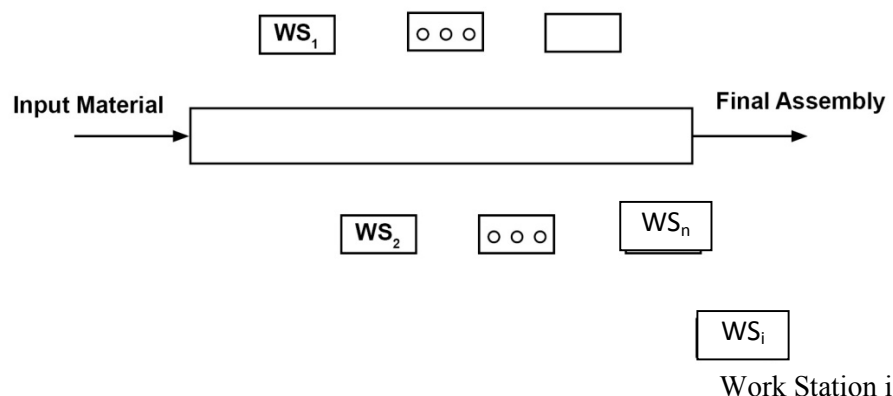
The flow shop employs special purpose equipment (designed specifically for the mass-scale production of a particular item or to provide a special service). The job shop contains general-purpose equipment (each unit is capable of doing a variety of jobs). The project, like the flow shop, requires a sequence of operations, except that the sequence lacks repetition. Each project operation is unique and seldom repeated. For example, the production line for automobiles is a flow shop; the machine shop that makes hundreds of different gears in batches of 50 at a time is a job shop; building a bridge or launching a satellite in space is a project.

This unit is concerned with the problems of mass production encountered in flow shops. Batch production and its problems, job shops and projects are discussed in further units of the Block.

Nature of Mass Production

It was Henry Word who in 1913 introduced the 'assembly line' and the notion of 'mass production'. It is erroneous to think that mass production means production in millions or for the masses, though this may be an outcome. Mass production refers to the manner in which a product is produced. This involves the decomposition of the total task into its minutest elements (shown usually on a precedence diagram) and the subsequent regrouping of these elements according to the norms of production. An assembly line consists of work stations in sequence where at each work station the above carefully designed portion of work is done. Mass production requires that all like parts of an assembly line be interchangeable and that all parts be replaceable, characteristics which permit production and maintenance of large quantities.

The assembly line is a production line where material moves continuously at a uniform average rate through a sequence of work stations where assembly work is performed. Typical example of these assembly lines are car assembly, electrical appliances, TV sets, computer assemblies and toy manufacturing and assembly. A diagrammatic sketch of a typical assembly line is shown in Figure 1. The arrangement of work along the assembly line will vary according to the size of the product being assembled, the precedence requirements, the available space, the work element and the nature of the work to be performed on the job.



Material movement between work stations could be **manual**, as for instance when operators sitting in a row pick up the part from the output of the previous operator, work on it and leave it in a bin to be picked up by the next operator; or through the **use of conveyors** which carry the part at a predetermined speed so that there is adequate time for each work station to complete its allocated share of work. There are various types of conveyor that are used in assembly lines; the most widely used are belt, chain, overhead, pneumatic and screw conveyors.

It may be of interest to note that assembly lines could have varying degrees of automation, starting from the purely manual on the one hand to the fully automated line on the other. However, the underlying principle of the assembly line and mass production remains unchanged, although the labour content may be reduced through robotization.

5.2 WHEN TO GO FOR MASS PRODUCTION

It is generally agreed that mass production is justified only when production quantities are large and product variety small. The ideal situation for mass production would be when large volumes of one product (without any changes in design) are to be produced continuously for an extended period of time. Thus the rate of consumption (or demand) of the product as compared to the rate of production decides whether continuous or batch production is called for. Obviously, only if the rate of demand is greater than or equal to the production rate, mass or **continuous production** could be sustained. If the rate of demand is less than the production rate, batch production with suitable inventory buildups could be resorted to.

Apart from the above consideration, the economics of the matter would have to be evaluated before deciding as to whether an assembly line is justified or not. This is illustrated by the following example.

Example 5.1

As a manager of a plant you have to determine whether you should purchase a component part or make it in the plant. You can purchase the item at Rs. 10 per piece. With an investment equivalent to an annual fixed cost of Rs 20,000 and a variable cost of Rs. 2.50 per piece an assembly line can be setup to manufacture the part. A third option open to you is to make the part at individual stations with an annual fixed cost of Rs. 10,000 and a variable cost of Rs. 5 a piece. Assuming that the annual demand is expected to be around 3500 units which alternative would you suggest?

Solution

The choice from the three alternatives (purchase, produce at individual stations, or employ an assembly line for production) is simplified by plotting

a cost vs quantity chart for these options. If Q is the quantity purchased or produced then total cost equals:

Rs. (IOQ) , if the part is purchased; Rs. $(10,000 + 5Q)$, if the part is made at individual stations; and

Rs. $(20,000 + 2.5Q)$ if the part is made on an assembly line. These cost functions are plotted in Figure II and the break-even points at quantity levels of 2000 and 4000 reveal the following decision rules:

For annual requirements in the range 0—2000, it is cheapest to buy,

For annual requirements' in the range 2000- 4000, it is cheapest to produce on individual stations, and only for annual requirements of 4000 or more, is an a assembly line justified.

Thus for **an annual** requirement of 3500, you should not recommend the installation of an assembly line.

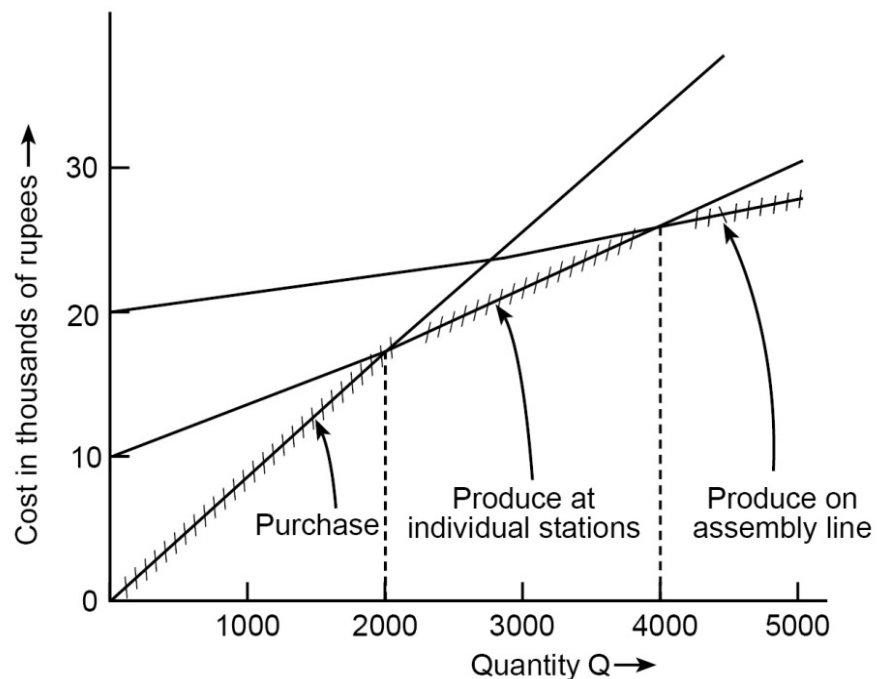


Fig II. Cost of Three Alternatives

5.3 FEATURES OF A MASS PRODUCTION SYSTEM

A mass production system operating as a continuous floor line exhibits certain desirable and undesirable features. These are summarised below:

Advantages

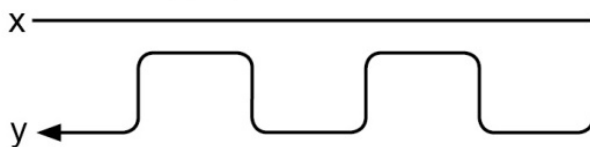
- 1) A smooth flow of **material** from one work station to the next in a logical order. **Although straight** line flow is common, other patterns of flow

exhibited in Figure III are also employed when constraints on space or movement so indicate.

(f) Combination of U and line flow pattern



(g) Combination of line flow and S type pattern



(h) Combination of flow and circular type



Figure III: Kinds of Flow Patterns

We have already exhibited the following common flow patterns in Unit 4 of Block I

- a) I-flow. (b) L-flow. (c) U-flow. (d) S-flow. (e) O-flow.
- 2) Since the work from one process is fed directly into the next, small in process inventories result.
- 3) Total production time per unit is short.
- 4) Since the work stations are located so as to minimise distances between consecutive operations, material handling is reduced.
- 5) Little skill is usually required by operators at the production line; hence training is simple, short and inexpensive.
- 6) simple production planning and control systems are possible.
- 7) less space is occupied by work in transit and for temporary storage.

Disadvantages

- 1) A breakdown of one machine may lead to a complete stoppage of the line that follows the machine. Hence maintenance and repair is a challenging job.
- 2) Since the product dictates the layout, changes in product design may require major changes in the layout. This is often expressed by saying that assembly lines are inflexible.
- 3) The pace of production is determined by the 'slowest' or 'bottleneck' machine. Line balancing proves to be a major problem with mass manufacture on assembly lines.
- 4) Supervision is general rather than specialized, as the supervisor of a line is looking after diverse machines on a line
- 5) Generally high investments are required owing to the specialized nature of the machines and their possible duplication on the line.

5.4 NOTION OF ASSEMBLY LINES AND FABRICATION LINES

It is useful to consider two types of line balancing problems:

- i) assembly line balancing, and
- ii) fabrication line balancing.

The distinction refers to the type of operation taking place on the line to be balanced. The term 'assembly line' indicates a production line made up of purely assembly operations. The assembly operation under consideration involves the arrival of individual component parts at the work place and the departure of these parts fastened together in the form of an assembly or sub-assembly.

The term 'fabrication line', on the other hand, implies a production line made up of operations that form or change the physical, or sometimes, chemical characteristics of the product involved. Machining or heat treatment would fall into operations of this type.

Although there are similarities between the problem of assembly line balancing and that of fabrication line balancing, the problem of balancing a fabrication line or machine line is somewhat more difficult than the assembly line balancing problem. It is not so easy to divide operations into relatively small elements for regrouping. The precedence restrictions are usually tighter in the fabrication line. An assembly operator may easily shift from one assembly job to another, but a machine tool may not be utilised for a variety of jobs without expensive changes in setup and tools.

Some methods by which the balance of fabrication operation times can be achieved are as follows:

- 1) changing machine speeds
- 2) using slower machines on overtime
- 3) providing a buffer of semi-finished parts at appropriate places
- 4) using mechanical device for diverting parts
- 5) methods improvement.

5.5 DESIGN OF AN ASSEMBLY LINE

The Broad Objective in Design

As you have just seen the two most important manufacturing developments, which led to progressive assembly are the concept of interchangeable parts and the concept of the division of labour. These permit the progressive assembly of the product, as it is transported past relatively fixed assembly stations, by a material handling device such as a conveyor. The work elements, which have been established through the division of labour principle, are assigned to the work stations so that all stations have nearly an equal amount of work to do. Each worker, at his or her station, is assigned certain of the work elements. The worker performs them repeatedly on each production unit as it passes the station.

The assembly line balancing problem is generally one of minimizing the total amount idle time or equivalently minimizing the number of operators to do a given amount of work at a given assembly line speed. This is also known as minimizing the balance delay. **'Balance delay' is defined as the amount of idle time for the entire assembly line as a fraction of the total working time resulting from unequal task time assigned to the various stations.**

Killbridge and Wester after studying the variation in idle times at stations caused by different assembly line balances concluded that high balance delay for an assembly line system for a specific product is caused by

- i) wide range of work element times
- ii) a large amount of inflexible line mechanisation and
- iii) indiscriminate choice of cycle times.

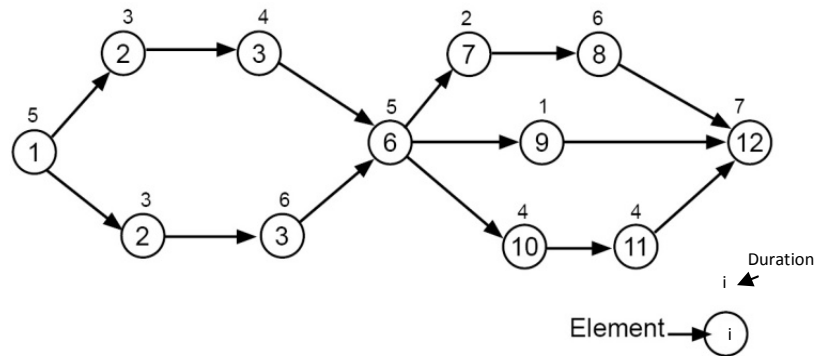
However, as we shall see, the cycle time is often dictated by a specific desired production rate, which may not lead to a low balance delay.

Division of Work into Parts: The Precedence Diagram

The total job to be done or the 'assembly' is divided into work elements. **A diagram that describes the ordering in which work elements should be performed is called a 'precedence diagram'.** Figure IV shows the precedence diagram for an assembly with 12 work elements. Note that tasks 2 and 4 cannot begin until task 1 is completed.

Moreover, there is no restriction on whether task 2 is done first or task 4. These two tasks are un-related meaning thereby that they may be done in

parallel or even with partial overlap. A task may well have more than one immediate predecessor. For example, in the precedence diagram of Figure IV task 12 has 3 immediate predecessors and cannot begin until all the three work elements 8, 9 and 11 are completed.



For example $\overset{6}{\textcircled{3}}$ means element 3 and duration 6

Figure IV: Precedence Diagram for an Assembly with 12 Elements

The ordering dictated by the precedence diagram may be the result of technological restrictions on the process or constraints imposed by layout, safety or convenience. The precedence diagram forms the basis for the grouping of work elements into work stations.

Grouping of Task for Work Stations end Efficiency Criteria

Depending on the desired production rate of the line, the cycle time (CT) or the time between the completion of two successive assemblies can be determined. This determines the conveyor speed in the assembly line or the time allocated to each operator to complete his share of work in a manual line.

The individual work elements or tasks are then grouped into work stations such that

- i) the station time (ST), which is the sum of the times of work elements performed at that station and should not exceed the cycle time, CT.
- ii) the precedence restrictions implied by the precedence diagram are not violated.

There **are many possible** ways to group these **tasks keeping the above** restrictions in mind and we often use criteria like line efficiency, balance delay and smoothness index to measure how good or bad a particular grouping is. These criteria are explained below:

- 1) **Line efficiency (LE):** This is the ratio of total station time to the product of the cycle time and the number of work stations. We can express this as

$$LE = \frac{\sum_{i=1}^K ST_i}{(K)(CT)} \times 100\%$$

where

ST_i = station time of station i

K = total number of work stations

CT = cycle time.

- 2) Balance delay (BD). This is a measure of the line inefficiency and is the total idle time of all stations as a percentage of total available working time of all stations.

Thus

$$BD = \frac{(K)(CT) - \sum_{i=1}^K ST_i}{(K)(CT)} \times 100\%$$

Balance delay is thus $(100 - LE)$ as a percentage.

- 3) Smoothness index (SI): This is an index to indicate the relative smoothness of a given assembly line balance. A smoothness index of 0 (zero) indicates a perfect balance. This can be expressed as:

$$SI = \sqrt{\sum_{i=1}^K (ST_{max} - ST_i)^2}$$

where

ST_{max} = maximum station time

ST_i = station time of station i

K = total number of work stations.

It may be noted that in designing an assembly line, the number of work stations, K , cannot exceed the total number of work elements N (in fact K is an integer such that $1 \leq K \leq N$). Also the cycle time is greater than or equal to the maximum time of any work element and less than the total of all work element times, that is

$$T_{max} \leq CT \leq \sum_{i=1}^N T_i$$

where

T_i is the time for work element i

N is the total number of work elements, T_{max} is the maximum work element time and CT is the cycle time.

There is yet no satisfactory methodology which guarantees an optimal solution for all assembly line balancing problems. The emphasis has been on

the use of heuristic procedures that can obtain a fairly good balance for the problem. For reviews of procedures available for assembly line balancing refer to Buffa and Kilbridge and Wester Two commonly used methods for obtaining a good balance for an assembly line balancing problem are presented in the next section.

5.6 LINE BALANCING METHODS

Kilbridge and Wester Method

In this procedure proposed by Kilbridge and Wester numbers are assigned to each operation describing how many predecessors it has. Operations with the lowest predecessor number are assigned first to the work stations. The procedure consists of the following **steps**:

- 1) Construct the precedence diagram for the work elements. In the precedence diagram, list in column I all work elements that need not follow others. In column II, list work elements that must follow those in column 1. Continue to the other columns in the same way. By so constructing the columns the elements within a column can be assigned to work stations in any order provided all the elements of the previous column have been assigned.

- 2) Select a feasible cycle time, CT. By a feasible time we mean one for which

$$T_{max} \leq CT \leq \sum_{i=1}^N T_i$$

- 3) Assign work elements to the station such that the sum of elemental times does not exceed the cycle time CT. This assignment proceeds from column 1 to II and so on, breaking intra column ties using the criterion of minimum number of predecessors.

- 4) Delete the assigned elements from the total number of work elements and repeat step 3.

- 5) If the station time exceeds the cycle time CT due to the inclusion of a certain work element, this work element should be assigned to the next station.

- 6) Repeat steps 3 to 5 until all elements are assigned to work stations.

Example 7.2: Design an assembly line for a cycle time of 10 minutes for the following 12 elements. Use Kilbridge- Wester Method.

Elements	1	2	3	4	5	6	7	8	9	10	11	12
Immediate predecessors	—	1	2	1	4	3,5	6	7	6	6	10	8,9,11
Duration (in minutes)	5	3	4	3	6	5	2	6	1	4	4	7

Solution: First of all the precedence diagram is completed as shown below in fig V using the above data. Grouping is done preliminarily as shown:

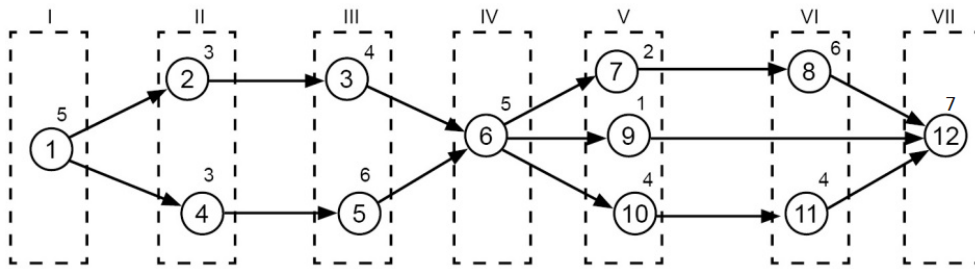


Figure V: Grouping of work elements Into Columns For Killbridge Westrer Method

Table 1

Station	Element i	T_i (in min)	Station sum (in min)	Idle time (in min)
I	1	5	5	$10 - 5 = 5$
II	2	3	6	4
	4	3		
III	3	4	10	0
	5	6		
IV	6	5	5	5
V	7	2	7	3
	9	1		
	10	4		
VI	8	6	10	0
	11	4		
VII	12	7	7	3

Total = 50 minutes

Assignment of work elements to stations (Wester and Kilbridge Method)

$$\text{Line Efficiency} = \frac{\text{Sum of station times of various work elements}}{\text{Total no. of work stations} \times \text{Cycle time}} = \frac{50}{7 \times 10} \times 100$$

$$= 71.43\% \text{ (not satisfactory)}$$

$$\text{Balance Delay} = 100 - 71.43 = 28.57\% \text{ (Quite high)}$$

$$\text{Smoothness index} = \sqrt{5^2 + 4^2 + 0^2 + 5^2 + 3^2 + 0^2 + 3^2}$$

$$= \sqrt{84} = 9.17 \text{ (quite high)}$$

We shall try yet another grouping as shown in the Fig. VI below reducing the number of work options from 7 to 6 now.

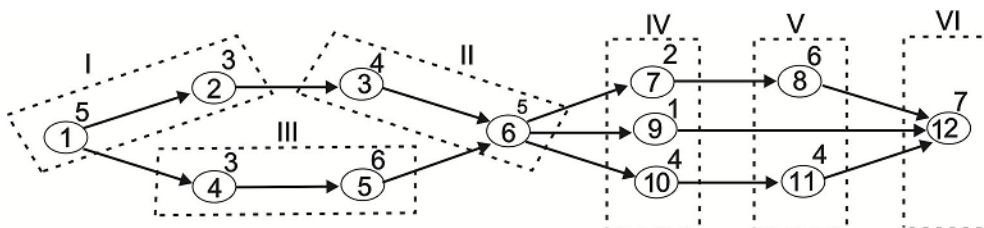


Fig. VI (Grouping (Re) of Work Elements.

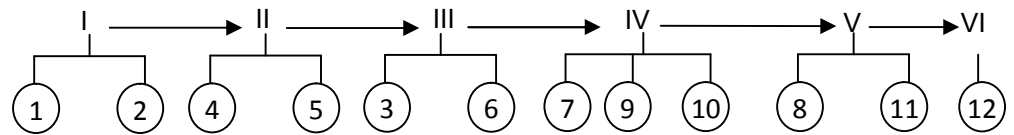


Fig. VI (a) Grouping of Work Elements.

Table 2

Station	Element i	T_i (in min)	Station sum (in min)	Idle time (in min)
I	1	5	8	$10 - 8 = 2$
	2	3		
II	4	3	9	1
	5	6		
III	3	4	9	1
	6	5		
IV	7	2	7	3
	9	1		
	10	4		
V	8	6	10	0
	11	4		
VI	12	7	7	3

Total = 50 minutes

$$\begin{aligned}
 \text{Line efficiency} &= \frac{50}{6 \times 10} \times 100 = 83.33\% \text{ (improvement)} \\
 \text{Balance Delay} &= 100 - 83.33 = 16.67\% \\
 \text{Smoothness index} &= \sqrt{2^2 + 1^2 + 1^2 + 3^2 + 0^2 + 3^2} = \sqrt{24} = 4.89
 \end{aligned}$$

From the above results, we see that there has been an improvement in the line efficiency from 71.43% to 83.33% (an improvement of 11.90%) and also the values of balance delay and smoothness index have gone down considerably which is a positive sign for line balancing. You may still try out yet another combination to improve upon the line efficiency of the above work stations.

It is interesting to note here that if the cycle time is reduced from 10 minutes to 9 minutes and regroupings are further attempted with suitable combinations, the line efficiency looks up to 92.6% figure. Regroupings are shown below for a cycle time of 9 minutes. Cycle time = 9 min.

Table 3

Station	Element i	T_i (in min)	Station sum (in min)	Idle time
I	1	5	8	1
	2	3		
II	4	3	9	0
	5	6		
III	3	4	9	0
	6	5		
IV	7	2	8	1
	8	6		
V	10	4	8	1
	11	4		
VI	9	1	8	1
	12	7		

Total = 50 minutes

$$\text{Line efficiency} = \frac{50}{6 \times 9} \times 100 = 92.59\%$$

$$\text{Balance delay} = 100 - 92.59 = 7.41\%$$

$$\text{Smoothness index} = \sqrt{1^2 + 0^2 + 0^2 + 1^2 + 1^2 + 1^2} = \sqrt{4} = 2 \text{ (Improvement)}$$

By reducing the duration of cycle time, the line efficiency can be further increased.

Helgeson and Birnie Method (Ranked Positional Weight Technique)

This method proposed by Helgeson and Birnie is also known as the ranked positional weight technique. It consists of the following steps:

- 1) Develop the precedence diagram in the usual manner.
- 2) Determine the positional weight for each work element (a positional weight of an operation corresponds to the time to the longest path from the beginning of the operation through the remainder of the network).
- 3) Rank the work element based on the positional weight in step 2. The work element with the highest positional weight is ranked first.
- 4) Proceed to assign work elements to the work stations where elements of the highest positional weight and rank are assigned first.
- 5) If at any work station additional time remains after assignment of an operation, assign the next succeeding ranked operation to the work station, as long as the operation does not violate the precedence relationships and the station time does not exceed the cycle time.
- 6) Repeat steps 4 and 5 until all elements are assigned to the work stations.

Example 7.3 Let us take up the illustration of balancing of the same assembly line by Helgeson and Birnie Method considered previously by the Kilbridge-Wester method. For the precedence diagram shown in Figure IV, and a desired cycle time of 10, we first construct the table of positional weights of all elements as shown. For example, the positional weight of operation 6 equals the maximum of $(5 + 2 + 6 + 7)$, $(5 + 1 + 7)$, $(5 + 4 + 4 + 7) = 20$, since there are 3 paths $(6 - 7 - 8 - 12, 6 - 9 - 12, 6 - 10 - 11 - 12)$ from the concerned operation to the end of the network. Following the above steps 4,5,6 we obtain the assignments of work elements shown in Table 4.

Table 4 (Helgeson and Birnie Method)

Element	Positional weight 1 (PW)	Element in descending order
1	Path 1-2-3-6-7-8-12 = 5+3+4+5+2+6+7 = 32 Path 1-4-5-6-10-11-12 = 5+3+6+5+4+4+7 = 34 Path 1-2-3-6-10-11-12 = 5+3+4+5+4+4+7 = 32 Path 1-4-5-6-7-8-12 = 5+3+6+5+2+6+7 = 34 Path 1-2-3-6-9-12 = 5+3+4+5+1+7 = 25 Path 1-4-5-6-9-12 = 5+3+6+5+1+7 = 27	Max of these = 34
2	27	(3) = 27
3	24	(5) = 24
4	29	(2) = 29
5	26	(4) = 26
6	20	(6) = 20
7	15	(7) = 15
8	13	(9) = 13
9	8	(11) = 8
10	15	(8) = 15
11	11	(10) = 11
12	7	(12) = 7

Table 5: Assignment of work elements to stations helgeson & Birnie method

Station	Element <i>i</i>	Positional wt	T_i	Station sum	Idle time
I	1	34(1)	5	8	2
	4	29(2)	3		
II	2	27(3)	3	9	1
	5	26(4)	6		
III	3	24(5)	4	9	1
	6	20(6)	5		
IV	7	15(7)	2	6	4
	10	15(8)	4		

V	8 11	13 (9) 11 (10)	6 4	10	0
VI	9 12	8 (11) 7 (12)	1 7	8	2
				50 minutes = Total	

Solution.

$$\text{Line efficiency} = \frac{50}{6 \times 10} \times 100 = 83.33\%$$

$$\text{Balance Delay} = 100 - 83.33 = 16.67\%$$

$$\text{Smoothness index} = \sqrt{2^2 + 1^2 + 1^2 + 4^2 + 0^2 + 2^2} = \sqrt{26} = 5.09$$

You may try the same with a cycle time of 9 minutes.

Example 7.4 Design an assembly line for a cycle time of 10 minutes for the following 10 work elements.

Element	1	2	3	4	5	6	7	8	9	10
Immediate predecessor	-	1	1	2,3	4	4	6	5	7,8	9
Duration (in min)	5	10	5	2	7	5	10	2	5	7

Use (a) Wester and Kilbridge Method.

(b) Helgeson and Birnie Method.

Calculate the line efficiency, balance delay and smoothness index in both cases.

Solution.

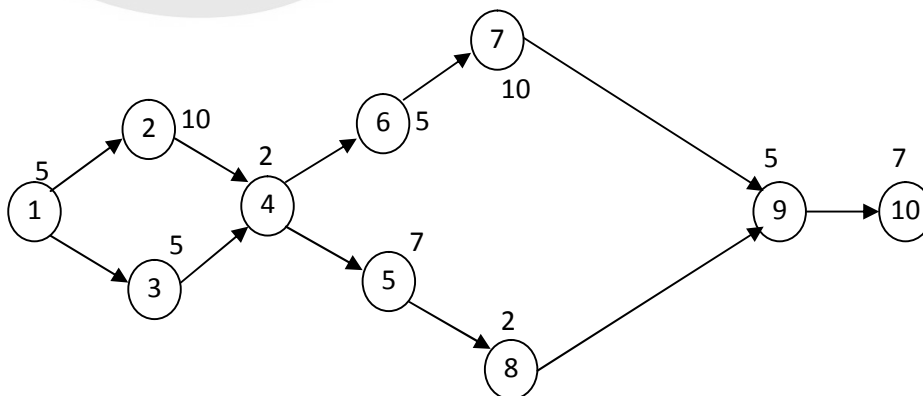


Fig. VII Precedence Diagram

Wester and Kilbridge Method (Cycle le time = 10 min)

Station	<i>i</i>	Idle time
I	(1) + (3) = 5 + 5 = 10	0
II	(2) = 10	0
III	(4) + (6) = 2 + 5 = 7	3
IV	(5) = 7	3
V	(7) = 10	0
VI	(8) + (9) = 2 + 5 = 7	3
VII	(10) = 7	3
Total = 58		

$$\text{Line efficiency} = \frac{58}{7 \times 100} \times 100 = 82.85\%$$

$$\text{Balance delay} = 100 - 82.85 = 17.15\%$$

$$\text{Smoothness Index} = \sqrt{0^2 + 0^2 + 3^2 + 3^2 + 0^2 + 3^2 + 3^2} = \sqrt{36} = 6$$

Helgeson and Birnie Method	<i>i</i>	Positional Weight
1	44 = 5 + 10 + 2 + 5 + 10 + 5 + 7	(longest time of path)
2	39 = 10 + 2 + 5 + 10 + 5 + 7	
3	34 = 5 + 2 + 5 + 10 + 5 + 7	
4	29 = 2 + 5 + 10 + 5 + 7	
5	21 = 7 + 2 + 5 + 7	
6	27 = 5 + 10 + 5 + 7	
7	22 = 10 + 5 + 7	
8	14 = 2 + 5 + 7	
9	12 = 5 + 7	
10	7 = 7	

Table 6

Station	<i>i</i>	Positional weight	T_i	Station sum	Idle time
I	(1)	(44)	5	5	10 - 5 = 5
II	(2)	39	10	10	0
III	(3) + (4)	34, 29	5 + 2	7	3
IV	(6)	27	5	5	5
V	(7)	22	10	10	0

VI	(5) + (18)	21, 14	7 + 2	9	1
VII	(9)	12	5	5	5
VIII	(10)	7	7	7	3
				58 minutes Total	

$$\text{Line efficiency} = \frac{58}{8 \times 10} \times 100 = 72.5\%$$

$$\text{Balance Delay} = 100 - 72.50 = 27.5\%$$

$$\text{Smoothness Index} = \sqrt{94} = 9.69$$

From the above example, for the same set of elements etc., Wester and Kilbridge Method groups more efficiently than Helgeson and Birnie Method.

Linear Programming Method of Line Balancing. Assume that a job is broken down into 6 elemental tasks and the total duration of all such tasks is 30 minutes. The cycle time, i.e., the length of time available to the workpiece on each work station is 10 minutes. Thus the minimum number of stations required are $30/10 = 3$ and the maximum number of work stations may be 6 that is equal to the number of tasks involved.

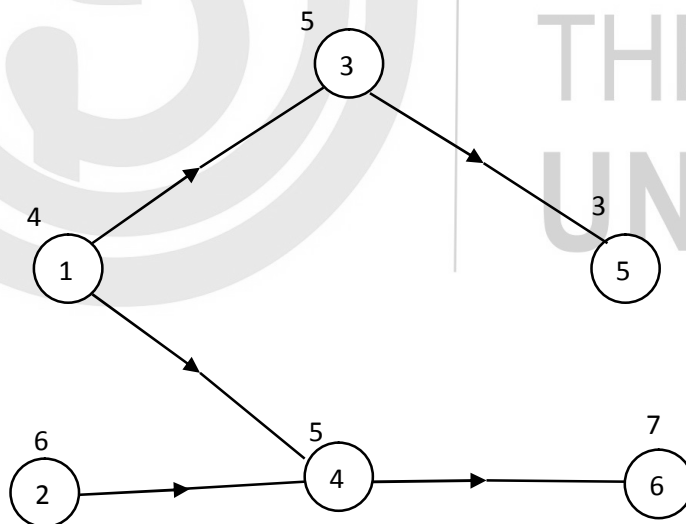


Fig. VIII Precedence Diagram

The problem now reduces, to find out the exact number of work stations needed and which tasks will be assigned to which station. Figure VIII shows the precedence diagram.

Three types of constraints equations namely cycle time constraint, step or task constraint and precedence constraints, will be formulated to solve the problem like an assignment model.

5.7 PROBLEMS AND PROSPECTS OF MASS PRODUCTION-VARIABLE WORK ELEMENT TIMES.

In both the line balancing methods discussed in the previous section, it was assumed that the work element times are constant. In practice these times may be varying randomly owing to factors like human variability, fatigue or carelessness on the operator's part. Even in case of machine operations, the set up or positioning time of the part or components could lead to random variations in the individual work element times. Since the assembly line is balanced for a given fixed set of work element times the effect of these variabilities are two-fold.

- i) greater idle time at some work stations, and
- ii) the reduction of the average production rate of the line.

In designing lines for random work element times with given means and variance, some modification of the deterministic line balancing method is adopted utilising the additional criterion that the probability of the station time exceeding the cycle time should be kept as low as possible. Some methods of probabilistic assembly line balancing are discussed by Elsayed and Boucher

Breakdowns at Work Stations

The mass production system consists of a number of stages in series at which some operations are being performed. A failure or a breakdown of one stage or work station will result in failure of the entire production system until repair is completed.

The result would be decreased production rate. This problem is handled in practice by providing

- i) efficient maintenance service so that the broken down units are repaired and put into service as soon as possible.
- ii) buffer storage of semi-finished goods between each pair of stages, so that the entire line does not stop due to the failure of one or more units.

The question of how much buffer storage to allocate between stages is of great practical importance — a higher buffer stock means greater tied up capital but a lower risk of runout and subsequent line stoppage due to breakdowns.

The decision to estimate the size of the buffer can be governed by one or more of the following criteria which consider as to what is the buffer size that:

- 1) maximises the production rate of the system
- 2) minimises the total production cost

3) maximises the availability of the production system.

The problem could in general be viewed as a multi-stage queuing system (Fig. IX) see for instance Elsayed and Boucher.

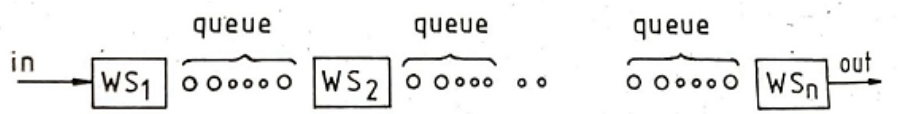


Figure IX: An Assembly Line with Buffers as a Multi-stage Questioning System

Multi-product Line

One of the major disadvantages with assembly lines is their relative inflexibility. A line is usually designed for one product and changes in design of the product are often difficult to accommodate on the line, unless suitable adjustments are made at work stations. But when similar products, in which a large percentage of the tasks are common, have to be manufactured, the possibility of the same production line for the products can be explored. Since tasks are fixed within stations, once balanced, it should be apparent that station times and efficiencies will vary with the products being produced. A great variety in these efficiencies might dictate that separate lines be utilised. In case a multi-product line is to be designed a common precedence diagram must be developed.

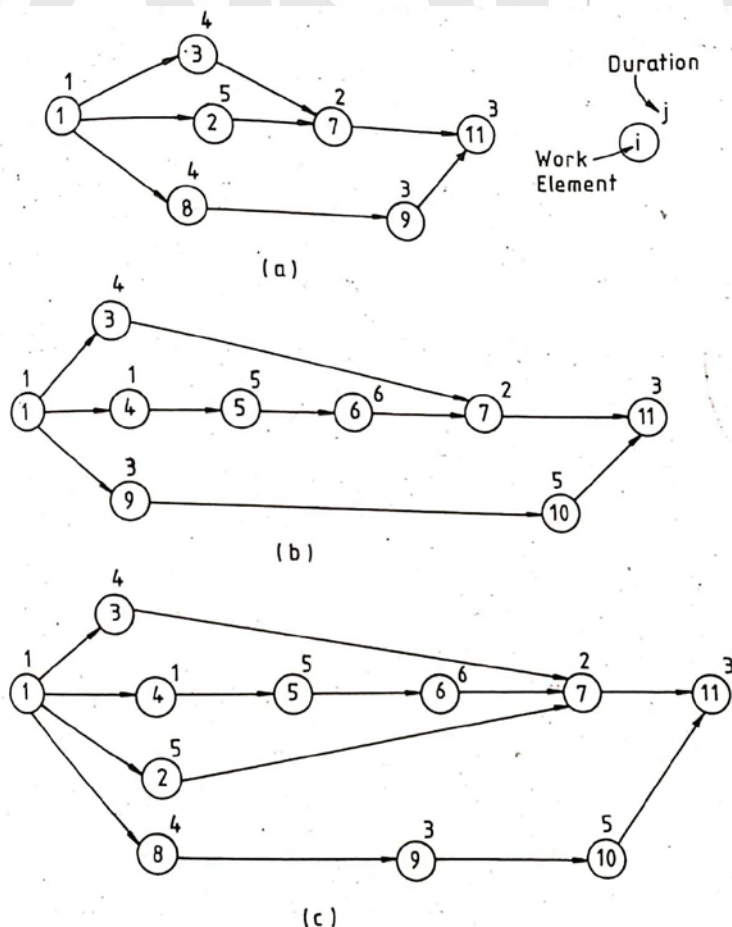


Fig. X Precedence Diagrams for a Two Product Line (a) Product 1, (b) Product 2, (c) Combined.

For instance precedence diagrams for a two product case are shown in Fig. X. For a cycle time of 10 the optimum solution is shown in Fig. XI. Notice that the line efficiencies are 73% and 100% for product 1 and 2 respectively. A computer assisted approach for multi product, Stochastic Line Balancing is described by Bedworth and Bailey.

Loss of efficiency over single product line but gain in equipment effectiveness is the trade off that must be evaluated in the mixed product line balance.

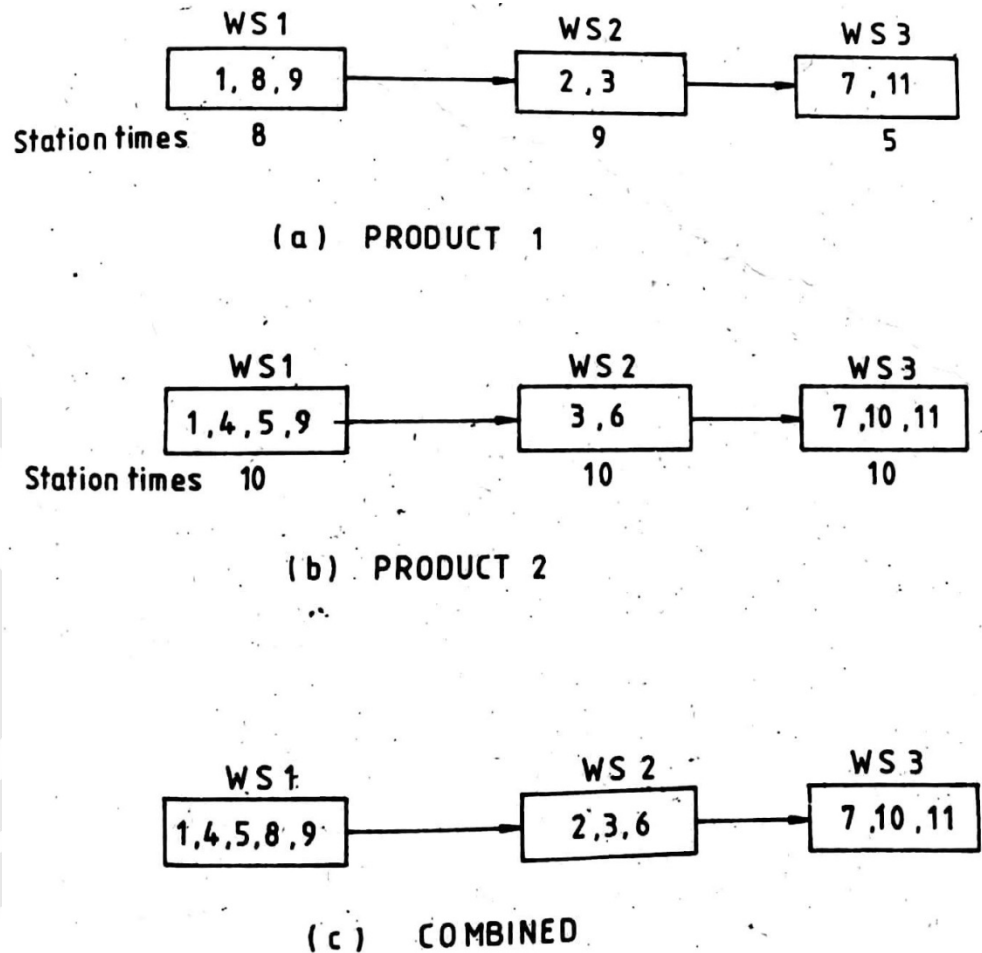


Fig. XI Work Station Assignment for the Two Product Assembly Line.

5.8 MODULAR PRODUCTION AND GROUP TECHNOLOGY

One criticism of manually operated assembly lines has been that they reduce a man to a mere cog in a machine. Surely you can imagine the boredom, monotony and fatigue of a man who spends all his time tightening the same bolt on a part in an assembly line. It has been found valuable to enlarge the scope of work of the worker so that he assembles a complete 'module', which in turn may be used on an assembly line to assemble a product or a number of different products sharing that particular module. This job enrichment results in greater job satisfaction for the operator by reducing the monotony of the job and giving the

operator a sense of accomplishment for assembling a complete module. In modular production we tend to specialise in the production of particular parts or activities that can then be included as components of more than one product or service. The reason for wanting to achieve such commonality is that one part or operation, if used in several products or services, can accumulate sufficient demand volume to warrant investment in a flow shop.

Group technology provides another aspect of the same basic idea. It refers to specialization in families of similar parts. Hence components requiring primarily turning operations, such as shafts, are collected in one group, while components **requiring** surface grinding and drilling operations, such as plates are assigned to a different group. These groups become the basis on which a traditional process plant layout can be reorganised into a group technology plant layout in which machines are arranged in such a way that each machine is assigned to the production of only one group of parts. **Group technology typically affects only component manufacture, not the assembly stage of production.**

For illustrative example of assembly lines using modular production and group technology refer to Salvendy.

5.9 AUTOMATION AND ROBOTICS

Mass production has been assisted to a large extent by automation and robotics in the recent past. Automation refers generally to the bringing together of three basic building blocks: machine tools, material handling and controls. Often a considerable amount of time is spent to load, machine and unload work and to convey it between the single operation machines. This restriction has been partly relieved by the development of the multiple spindle machine. With this machine, a single motor driving several spindles through a gear train allows multiple operations to be performed by one machine. Machining time cycles does not change, but more machining operations can be performed within each cycle, and several machining operations can be performed on one machine by a single operator.

Automatic work piece indexing and transfer of work pieces from station to station has made it possible for one operator to control the work performed at several machining stations. Also the operator is able to load and unload at the load station while machining is going on.

Another trend with automation has been the use of industrial robots to perform some of the functions that were earlier done by manual operators.

An ‘industrial robot’, as defined by the Robot Institute of America, is a programmable, multi-function manipulator designed to move material, parts, tools or specialized devices through variable programmed motions

for the performance of a variety of tasks. What separates an industrial robot from other types of automation is the fact that it can be reprogrammed for different applications; hence a robot falls under the heading of flexible automation', as opposed to 'hard' or dedicated automation.

Industrial robots consist of three basic components:

- 1) The manipulator (or arm), which is, a series of mechanical linkages and joints capable of movement in various directions to perform the work task.
- 2) The controller, which actually directs the movements and operations performed by the manipulator. The controller may be an integral part of the manipulator or may be housed in a separate cabinet
- 3) The power source, which provides energy to the actuators on the arm. The power source may be electrical, hydraulic, or pneumatic.

Major reasons for use of robots **in industry** are increased productivity, adaptability, safety, ease **of training**, return on investment and greater reliability. Robots are currently in operation in welding and assembly, drilling and routing, inspection, material handling, **machine loading, die casting and a variety of other applications.**

5.10 SUMMARY

In this unit we have presented the concept of mass production which essentially **involves** the **assembly of** identical (or inter-changeable) parts of components into the final product in stages at various work stations. The relative advantages and disadvantages of mass or flow production are discussed and conditions favouring the installation of such a system are identified.

How to design an assembly line starting from the work breakdown structure to the final grouping of tasks at work stations is also discussed using two commonly used procedures—the Kilbridge-Wester heuristic approach and the Helgeson-Birnie approach. Various problems with assembly lines including variable work element times, breakdowns at work stations and multi-product line are discussed.

The concepts of modular production and group technology has also been touched to indicate how flexibility can be introduced in mass or flow manufacture. Finally, the role of automation and the use of industrial robots in mass production has been discussed.

5.11 KEY WORDS

Assembly line: A sequence of work stations where parts or components of a product are progressively worked on to produce the finished product.

Balance delay: The total idle time of all stations as a percentage of total available working time of all stations in an assembly line.

Cycle time: The time after which a finished product comes off the assembly line. It would equal the time of the bottleneck operation or the maximum station time.

Fabrication line: A production line made up of machining or other operations rather than assembly of components or parts.

Flow shop: A manufacturing system in which machines and other facilities are arranged on the basis of product flow (generally used for large production volumes and less product variety).

Group technology: A manufacturing philosophy in which similar parts are identified and grouped together to take advantage of their similarities in design and manufacture.

Job shop: A manufacturing system in which similar machines and equipment are clubbed in departments and each job handled takes its own route. (Generally used for low production volumes with great product variety.)

Line balancing: The problem of assigning tasks to work stations in an assembly line in a way that the task times for all stations are equalized as far as possible.

Line efficiency. The ratio of the actual working time at all stations of an assembly line to the total allocated time at all stations.

Mass production: A manufacturing system based on interchangeable parts and the concept of the division of labour to produce generally large quantities of a product through successive operations/assemblies carried out at a sequence of work stations in an assembly line.

Modular production: The principle employed in modular production is to design, develop and produce the minimum number of parts or operations (called 'modules') that can be combined in the maximum number of ways to offer the greatest number of products or services.

Precedence diagram: A diagram showing the elemental tasks and the order in which they may be performed. This specifies the technological and other restrictions that must be respected while designing an assembly line.

Production system: An arrangement by which inputs (like men, machines, material, money, information and energy) are transformed into useful goods or services.

Project: A typical production system where production is infrequent (often, only once) characterised by a number of related jobs to be done with precedence restrictions.

Smoothness index: ‘The square root of the sum of squares of idle time at all work stations in an assembly line. This is an index to indicate the relative smoothness of a given assembly line balance. The lesser the better.

Station Time: ‘The sum of the element times of all tasks allotted to a work station in an assembly line.

Work element: The smallest portion of work identified during the work breakdown analysis of a job. It is uneconomical or technologically absurd to further subdivide the work elements, in designing an assembly line.

Work station: A place or stage in an assembly line where designated work (a combination of work elements) is performed on the part or components of the product.

5.12 SELF-ASSESSMENT EXERCISES

- 1) What are the key elements of mass manufacture?
- 2) Draw a precedence diagram for changing a car tyre. Discuss the way in which this job could be done with a flow shop configuration. Suggest a possible division of labour that would produce a reasonable line balance.
- 3) Design an assembly line for a cycle time of 10 minutes for the following 10 work elements

Elements	1	2	3	4	5	6	7	8	9	10
Immediate Predecessors	-	1	1	(2,3)	4	4	6	5	(7,8)	9
Duration in minutes	5	10	5	2	7	5	10	2	5	7

Use

- a) Kilbridge and Wester method
- b) Helgeson and Birnie method.

Calculate the line efficiency, balance delay and smoothness index in both the cases.

Ans (a) 82.85%, 17.15%, 6 (b) 72.50%, 27.5%, 9.69

- 4) Repeat problem 3 for a cycle time of 12 minutes.
- 5) Why do we use buffers between stations in assembly lines? What would be the implications of
 - a) too large a buffer?
 - b) too small a buffer?

Suggest a method by which the optimal buffer quantities could be found out.

- 6) An assembly line is relatively inflexible. Explain how by using the notion of modular production or group technology, flexibility can be attained in a flow shop configuration.
- 7) A toy manufacturer intends to make 10,000 pieces per year in the 2000 hours of regular time each year. He has identified 16 work elements with the following precedence restrictions and durations:

Table 7

Element	Immediate predecessor	Standard time (hrs/piece)
1	—	0.14
2	1	0.01
3	2, 15	0.13
4	3	0.12
5	4	0.01
6	5, 12	0.10
7	6, 16	0.07
8	1	0.06
9	8	0.17
10	9	0.17
11	10, 14	0.20
12	11	0.17
13	8	0.03
14	13	0.09
15	1	0.20
16	5	0.05

- a) Draw a precedence diagram for the assembly of toys.
- b) Design an assembly line suitable for the toy manufacturer.
- c) Compute the line efficiency, balance delay and smoothness index for your design in (b) above.

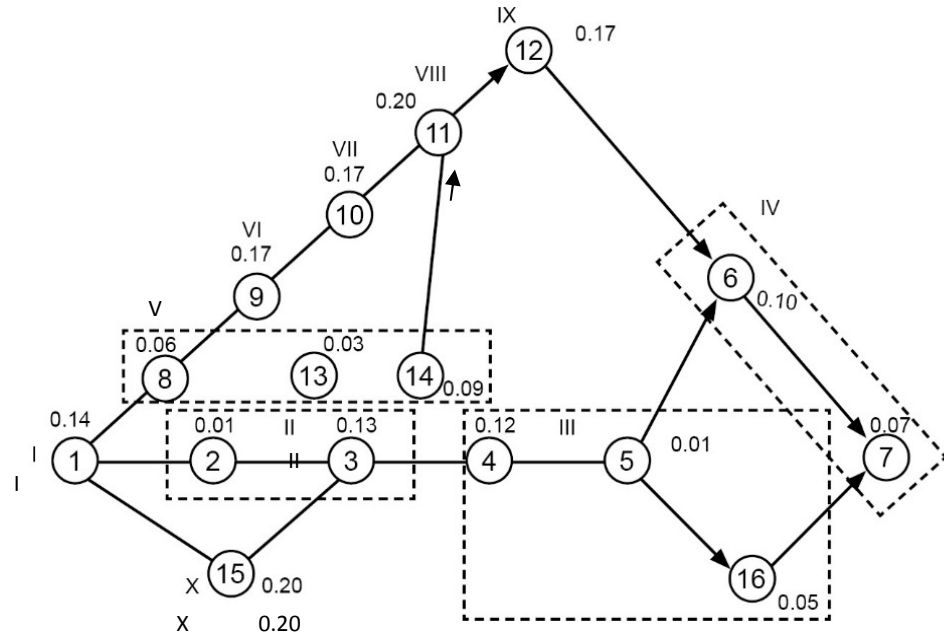


Fig. 2.33.

Table 8. Precedence Diagram (grouping of elements)

Station	Element (i)	T_(i) (hrs)	Station sum (hrs)	Idle time (hr)
I	(1)	0.14	0.14	0.20-0.14=0.06
II	(2)+(3)	0.01+0.13	0.14	0.06
III	(4)+(5)+(16)	0.12+0.01+0.05	0.18	0.02
IV	(6)+(7)	0.10+0.07	0.17	0.03
V	(8)+(13)+(14)	0.06+0.03+0.09	0.18	0.02
VI	(9)	0.17	0.17	0.03
VII	(10)	0.17	0.17	0.03
VIII	(11)	0.20	0.20	0
IX	(12)	0.17	0.17	0.03
X	(15)	0.20	0.20	0

$$\text{Time per price} \frac{2000}{10000} = 0.20\text{hrs/pc} = \text{cycle time}$$

$$\text{Line Efficiency} = \frac{1.72}{\text{No. of stations} \times \text{Cycle time}}$$

$$= \frac{1.72}{10 \times 0.20} \times 100 = 86\%$$

$$\text{Balance Delay} = 100 - 86 = 14\%$$

$$\text{Smoothness Index} =$$

$$\sqrt{(0.06)^2 + (0.06)^2 + (0.02)^2 + (0.03)^2 + (0.02)^2 + (0.03)^2 + (0.03)^2 + 0^2 + (0.03)^2 + 0^2}$$

$$= \sqrt{0.0116} = 0.1077 \text{ Ans.}$$

5.13 FURTHER READINGS

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UNIT 6 PLANNING AND CONTROL FOR BATCH PRODUCTION

Objectives

After completion of this unit, you should be able to:

- understand the nature of batch production and the circumstances under which it is used, appreciate that batch size determination, sequencing and scheduling are the major problems in batch production and determine the optimum batch sizes for single and multi-product case produced on a single machine
- appreciate the problems of aggregate production planning and master schedule determination, get an idea of material requirements planning and its function in an organization, become familiar with the line of balance as a valuable tool for monitoring and control in batch production and become aware of new developments like Kanban and Flexible Manufacturing Systems.

Structure

- 6.1 Introduction
- 6.2 Features of Batch Production
- 6.3 How to Determine the Optimum Batch Size
- 6.4 Aggregate Production Planning
- 6.5 Material Requirements Planning
- 6.6 The Line of Balance (LOB) for Production Control and Monitoring
- 6.7 Problems and Prospects of Batch Production
- 6.8 Summary
- 6.9 Key Words
- 6.10 Self-assessment Exercises
- 6.11 Further Readings

6.1 INTRODUCTION

When a variety of products is to be made and the volumes of production are not large enough to justify a separate line for each product, production in batches is often resorted to. Batch production implies that general purpose machines are utilised for the production of different products. Material flow tends to be more complex in such systems than in mass production systems.

The layout plan for such systems has to be carefully designed keeping in mind the diversity of products and their individual flow patterns and production volumes. Naturally, in such systems the production times are larger as compared to those in mass production. Batch production is distinguished from the Job Shop as follows:

In batch production a continuous demand for certain products exists, but because the rate of production exceeds the rate of demand, there is a need to produce products in batches. The scheduling problem here is concerned with determining the batch sizes for products and the order in which they should be produced.

In job production a stream of orders has to be processed on common facilities or production centres, each job having its own unique specifications and requirements in terms of production resources. A job may consist of a single item or a batch of identical items. The scheduling problem here is concerned with setting the sequence with which jobs should be processed at each production centre. Of the various problems in batch production we shall, in this unit, address ourselves to:

- the problem of determining optimal batch sizes
- aggregate production planning
- disaggregation of the aggregate plan to determine the master production schedule
- material requirements planning to achieve a given master production schedule, the problem of production control using the line of balance (LOB) in batch production
- some recent concepts in batch and Discrete Parts Systems.

6.2 FEATURES OF BATCH PRODUCTION

Unlike mass production systems which tend to be organised as product layouts with machines or equipment arranged according to the product flow, batch production normally is done employing a process layout. Here similar machines or equipment are grouped in departments and different jobs will follow their own route depending on requirements. Apart from the greater flexibility afforded by process layouts as compared to product layouts some of the advantages and disadvantages of process layouts are summarised below:

Advantages:

- i) Better utilisation of machines is possible; consequently, fewer machines are required.
- ii) A high degree of flexibility exists vis-a-vis equipment or manpower allocation for specific tasks.
- iii) Comparatively low investment in machines is needed.
- iv) There is generally greater job satisfaction for the operator owing to the diversity of jobs handled.
- v) Specialised supervision is possible.

Disadvantages:

- i) Since longer and irregular flow lines result, material handling is more expensive.
- ii) Production planning and control systems are more involved.
- iii) Total production time is usually longer.
- iv) Comparatively large amounts of in-process inventory result.
- v) Space and capital are tied up by work in process.
- vi) Because of the diversity of jobs in specialised departments, higher grades of skill are required.

In addition to these features which are characteristic of the layout generally adopted in batch production, questions like what should be the size of the batch? or how should various batches be sequenced? arise typically. Although such decisions may be made in practice, either in an adhoc manner or by using certain rules of thumb derived from past experience, we demonstrate below a more rational outlook to arrive at the 'optimal' decisions pertaining to batch size.

6.3 HOW TO DETERMINE THE OPTIMUM BATCH SIZE

Single Product Case

Let us consider a situation for the production of a single product on a machine under the following set of assumptions.

- there is a continuous demand for the product at rate D units per year
- production rate for the product is P units per year ($P > D$)
- set up cost per batch of size Q is fixed at A (independent of Q)
- unit variable cost of production is C per piece

Figure 1: Single Product Model with Constant Demand Rate and no Shortages

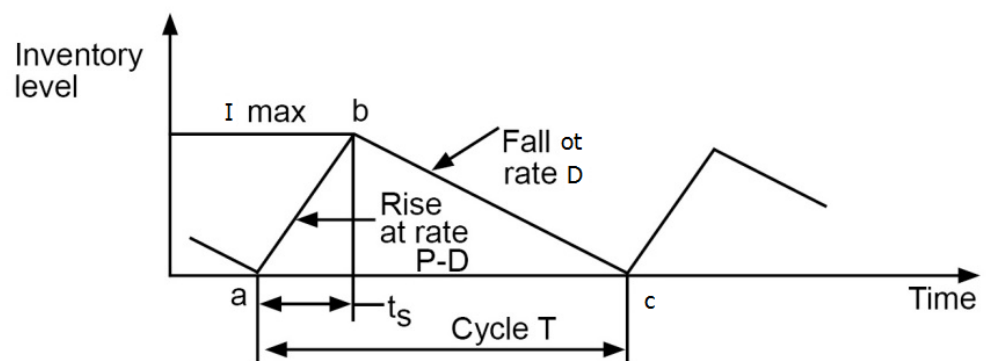


Fig. I: Single product model with constant demand and no shortages

- inventory carrying cost per unit per year (Rs./unit/year) = $h = i C$ where i is the annual inventory carrying cost rate

- no shortages are allowed

Figure I shows the change in inventory level within a cycle T. When production starts at point a, the inventory level will increase at a rate P-D (can you see why?) until the maximum is attained at point b. The inventory level will decrease at a rate D during the rest of the cycle till point c is reached at which a new batch of size Q is initiated and a similar cycle continuous.

It is easy to see from Figure I that

$$\text{Time to produce a lot } Q = t_s = Q/P \quad \dots\dots\dots (6.1)$$

$$\text{Maximum inventory level} = I_{\max} = t_s (P-D)$$

$$= \frac{Q}{P} (P - D)$$

$$= Q (1 - D/P) \quad \dots\dots\dots (6.2)$$

The total cost is built up of two conflicting components—the set up cost (which favours large batch sizes) and the inventory holding cost (which favours small batch sizes). Our approach, therefore, is to develop an expression for the total annual cost in terms of the decision variable (which is the batch size Q in this case) and then to mathematically determine the optimum.

This can be done as follows:

The average cost per cycle of length T is the sum of the set up cost, item variable cost and the carrying cost

$$= A + CQ + h T I \quad \dots\dots\dots (6.3)$$

where I is the average inventory over the cycle T. The average inventory I over the cycle T may be determined from Figure I as the area of the triangle abc divided by T

$$I = 1/2 \frac{TI_{\max}}{T}$$

$$= 1/2 \times Q (1 - D/P) \text{(utilising equation 6.2)} \quad \dots\dots\dots (6.4)$$

The total annual cost TC(Q), is obtained by multiplying equation (6.3) by the number of orders per year, D/Q. By substituting $h=iC$, we obtain

$$TC(Q) = \frac{AD}{Q} + CD + iCI \quad \dots\dots\dots (6.5)$$

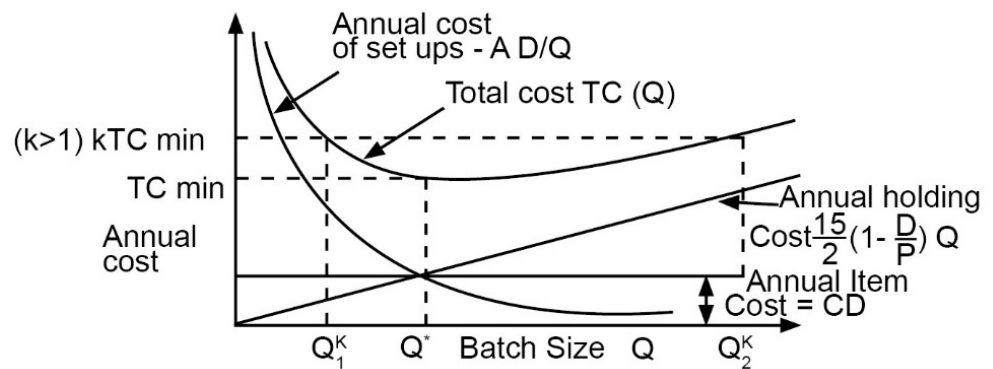


Fig. II: Total Annual cost as a function of batch size.

Q_1^k and Q_2^k are some batch sizes and k is some quantity assumed ($k > 1$).

Substituting for I utilising equation (6.4).

$$TC(Q) = \frac{AD}{Q} + CD + \frac{iC}{2}Q\left(1 - \frac{D}{P}\right) \dots\dots\dots (6.6)$$

Differentiating this w.r.t Q and equating the result with o (zero), we get

$$\frac{dTC(Q)}{dQ} = 0 \text{ yields the optimal batch size } Q^* \text{ as}$$

$$Q^* = \sqrt{\frac{2AD}{iC\left(1 - \frac{D}{P}\right)}} \dots\dots\dots (6.7)$$

The total annual cost (equation 6.6) is plotted in Figure II.

The optimum batch size Q^* determined from the above equation 6.7 may have to be modified in practice to suit procurement, storage or machine capacity constraints which have been ignored in the above model. Figure II illustrates how a range of batch sizes (from Q_1^k to Q_2^k) may be determined so that the total annual cost does not exceed a certain specified cost level (say k times the minimum cost $TC_{\min}$, $k > 1$).

Also notice that because of the relatively steep nature of the total cost function to the left of the optimum Q^* , as compared to the right, Q_1^k is closer to Q^* than Q_2^k .

Example 6.1

Determine the optimum batch size for an item produced on a manufacturing facility with the following data:

Consumption rate = 500 items/month, Production rate = 1500 items/months
Storage costs = Rs. 100 per unit per year, Setup charges per batch = Rs. 2000.

Item cost = Rs 1000 per unit= C

What is the breakup of annual item cost, setup cost and holding cost at the optimum?

Ans: (i) $Q^0=600$ (ii) Annual item cost = $C.D=Rs\ 60,00,000$ per year
(iii) set-up cost = $Rs\ 20,000/yr$ (iv) Holding cost = $Rs\ 20,000/yr$

Multi-product Case

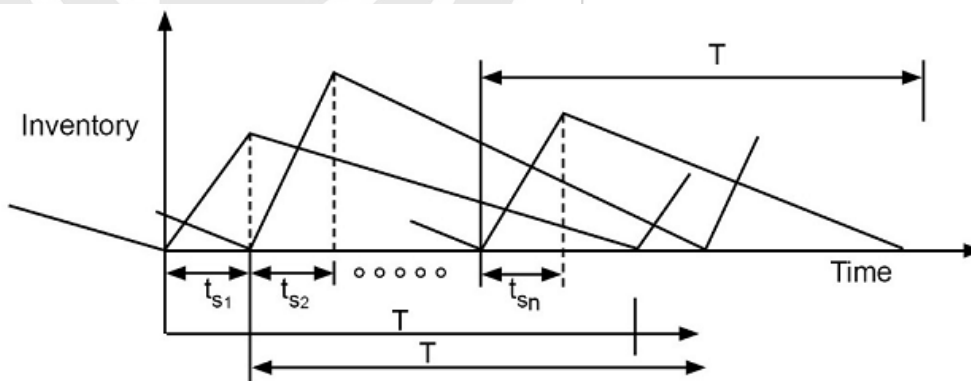
We shall consider a situation where n items are manufactured on a single machine, with the restriction that there is a common cycle time T for all the items. The n batches are thus phased within the common cycle. Assuming no shortages, the total annual cost for this multi-item case can be estimated as the sum of the total annual cost of each item independently. Extending the model for the single product case by including a subscript j for the j th product ($j=1,2,\dots,n$) we have for the total annual cost (analogous to $TC(Q)$ in eqn. 6.6):

$$TC(Q_1, Q_2, \dots, Q_n) = \sum_{j=1}^n \left(C_j D_j + \frac{A_j D_j}{Q_j} + \frac{i C_j Q_j}{2} \left(1 - D_j / P_j \right) \right) \dots \dots \dots (6.8)$$

As seen from Figure III a feasible schedule can be generated with a common cycle T , if the time for production of all batches does not exceed the common cycle time. In the absence of set up time for a lot this is equivalent to:

$$t_{s1} + t_{s2} + \dots + t_{sn} \leq T \dots \dots \dots (6.9)$$

Figure III: Production of Multiple Batches on a Single Machine with a Common Cycle



Since the time required to produce the batch of j th product $= t_{sj} = \frac{Q_j}{P_j}$ and

because $T = Q_j / D_j$, condition 6.9 may be expressed as:

$$\frac{D_1}{P_1} + \frac{D_2}{P_2} + \dots + \frac{D_n}{P_n} \leq 1 \dots \dots \dots (6.10)$$

Equation 6.10 may be interpreted as a resource feasibility check to determine if all n items can be scheduled on a single machine. In case the left hand side

of eqn. 6.10 exceeds one and equals say 2.4 in a particular case, it indicates that 3 (the integer just exceeding 2.4) is the minimum number of machines needed for scheduling all items under the assumption of a common cycle time.

We can convert the annual total cost expression of eqn. (6.8) into the following by using $Q_j = TD_j$

$$TC(T) = \sum_{j=1}^n \left(C_j D_j + \frac{A_j}{T} + \frac{i C_j D_j}{2} T \left(1 - \frac{D_j}{P_j} \right) \right) \dots \quad (6.11)$$

By means of the assumption of a common cycle time we have in effect only one decision variable (T).

The optimum T^* can be found by putting $\frac{dTC(T)}{dT} = 0$, which yields

$$T^* = \sqrt{\left(\sum_{j=1}^n A_j \right) / \left(i \sum_{j=1}^n D_j \left(1 - D_j / P_j \right) \right)} \dots \dots \dots (6.12)$$

Once T^* is obtained the optimum batch sizes $Q^*_1, Q^*_2, \dots, Q^*_n$ can easily be found out by using $Q^*_j = T^* D_j, j = 1, \dots, n$.

Example 6.2

A company is concerned with the production of four products on the same equipments. The relevant data is shown in Table 1.

- Determine the lot sizes of the products individually.
- What would be the difficulty in scheduling the above “optimum” lot sizes on the machine?
- Under the assumption of a common cycle time, determine the lot sizes. Assume that there are 240 working days in a year.

Product (j)	Demand rate (units/year) (D_j)	Production rate (units/year) P_j	Inventory Cost Rs./unit/year iC_j	Set up cost (Rs.) A_j
1	1500	12,000	Rs. 50.00	Rs. 90
2	1134	5,000	Rs. 108.00	Rs. 210
3	2016	6,667	Rs. 75.00	Rs. 165
4	2716	8,000	Rs. 67.50	Rs. 135

Assume that there are 240 working days in a year.

Solution

- a) Under this condition the individual lot sizes may be determined by using eqn.6.7 that is

$$Q^* = \sqrt{\frac{2 A_j D_j}{i C_j (1 - D_j / P_j)}}$$

The results are summarised in Table 2.

Table 2: Individual Economic Lot Sizes for the four Products

Product (j)	Economic lot size Q_j^*	Production days per lot (Q_j^* / P_j)	Cycle time T_j^* in days = (Q_j^* / D_j)
1	78.6 [#]	1.57 [#]	12.6 [#]
2	75.5	3.62	15.9
3	112.8	4.06	13.4
4	128.3	3.85	11.3
Total		13.10	

$$78.6^{\#} = \sqrt{\frac{2 \times 90 \times 1500}{50 \times \left(1 - \frac{1500}{12000}\right)}} = 78.6, \quad 1.57^{\#} = \frac{240 \times 78.6}{12000}$$

$$\text{and } 12.6^{\#} = \frac{240 \times 78.6}{1500}$$

- b) A look at Table 2 indicates that scheduling the four products on the machine in sequence would take a minimum of 13.10 days (the total of the production days for all the lots). Note that an economic lot of product 4 will last only 11.3 days whereas a lot of product 2 will last for 15.9 days. Thus there would be uncontrollable shortage and surplus with this scheme of scheduling.

This difficulty is overcome when we consider a common cycle time for all the products.

- c) Under the common cycle category we obtain the solution by using eqn. 6.12. Computations are simplified if we tabulate the numerator and denominator terms needed under the radical sign on the right hand side in eqn. 6.12. This is shown in Table 3. The common cycle equals 0.0557 year (=0.0557 x 240 =13.37 working days) out of which 13.26 days are utilised for the production of the four product lots as indicated in Table 3.

Table 3: Results under a common of cycle policy

Product	Set up cost A_j	$(1 - D_j/P_j)$	$iC_jD_j(1 - D_j/P_j)$	$Q_j^* = T^*D_j$	Production days per lot (Q_j^*/P_j)
1	90	0.8750	65,625.00	84	1.68
2	210	0.7732	94,695.40	63	3.02
3	165	0.6976	105,477.10	112	4.03
4	135	0.6605	121,089.50	151	4.53
Total	600		386,887.00		13.26

You could also check that the feasibility condition of equation 6.10 is in fact satisfied

$$\left(\frac{D_1}{P_1} + \frac{D_2}{P_2} + \frac{D_3}{P_3} + \frac{D_4}{P_4} = 0.1250 + 0.2268 + 0.3024 + 0.3395 = 0.9937 < 1 \right)$$

$$\text{Common Cycle Time} = \sqrt{\frac{2 \times 600}{386,886}} = 0.0557 \text{ yr} = 0.0557 \times 240 = 13.37 \text{ working days.}$$

6.4 AGGREGATE PRODUCTION PLANNING

The Purpose

Customer demand enters the production system as units of products. Aggregate production planning is concerned with developing the work force and machine time allocation to meet a given demand schedule over the planning horizon (generally the next 3 to 6 months). The purpose of this exercise is to produce at 'aggregate' plan in terms of the overall production of all products combined such as production in tons of steel or litres of paint which would have to be 'disaggregated' to yield individual product schedules.

When planning work force and related activities to conform to a given demand schedule, it is necessary to balance the cost of building and holding inventory against the cost of adjusting activity levels to fluctuations in demand. Figure IV shows a hypothetical cumulative demand pattern and two alternative production strategies.

Alternative-1 uses a constant work force level (i.e. constant production output rate). Since the production rate is greater than the expected demand rate in the earlier production periods, cumulative production will exceed cumulative demand resulting in a significant inventory carrying cost. Conversely significant shortage cost may result when the cumulative demand exceeds the cumulative production.

Alternative-2 is a strategy to produce as per demand so that the inventory carrying costs are minimised. This alternative requires constantly

adjusting the work force levels or paying significant overtime cost during the high demand periods.

These are two extreme alternatives. The optimal alternative is the one that minimises the total cost of the inventory and the cost of adjusting the work force level.

The primary output of the aggregate planning process is a master schedule, which describes the number of units to be produced during each period and the work force levels required by period.

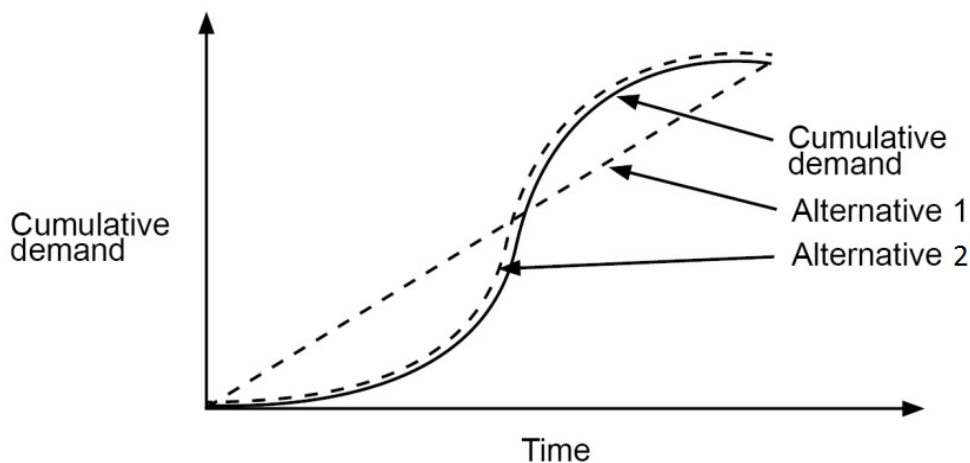


Fig. IV: Two Alternative Production Schedules for Meeting Demand

A Brief Review of Approaches

Perhaps the simplest approach to aggregate production planning is graphical in which the cumulative demand is plotted as shown in Figure IV and alternative production plans (shown as dotted lines) are compared in terms of their costs and the most economical one is adopted. This approach suffers from the drawback that chooses the best plan from the ones considered and not from 'all' possible plans which in fact could be infinitely large and difficult to conceive.

The above limitation is to some extent taken care of in mathematical optimisation models. The approach for finding the optimal alternative (master schedule and work force level) in such a case is to develop a total cost function which contains the major cost components of the production facility. This cost function is to be minimised while subject to constraints. The linearity or non-linearity of the cost function and constraints determines the solution approach to the problem. Multi-period production planning models can be treated as network flow problems and solved by special procedures (See for instance, Johnson and Montgomery).

Other methods for dealing with the aggregate production planning problem could be heuristic rules or computer search procedures. A review of approaches to aggregate production planning may be found in Buffa, Eilon, Elsayed and Boucher.

Disaggregation to a Master Schedule

The production facility considered in example 3 is a chemical plant which is shared by products A and B. Simultaneous production is not possible. Therefore, we should plan the production of each product by alternating the use of the facility between products. A disaggregation of example 3 requires the determination of the batch size of products A and B that will be produced each time a change-over occurs.

The necessity and desirability of disaggregation is situation dependent. In situation where product demand estimates are likely to differ from actual values, plant management may proceed to set hiring policies based on aggregate plant hour production requirement, with the assumption that forecast errors for individual products will be offset in the aggregate.

In situations where demand estimates are precise it is reasonable to consider a complete disaggregation of their production plan to the individual product level. When such disaggregation is done, the resulting output is called a master schedule, a schedule of the time bound completion of production.

Let us assume that in Example 3 the demand forecast by product is reasonably precise and we wish to disaggregate the plan. The aggregate solution has minimised two costs, the production cost and the inventory carrying cost. Given the solution the only remaining cost to be considered is the setup cost incurred each time production is switched between products. With only two products to be considered, a simple approach to minimising set up cost is to minimise the total number of set ups scheduled over the planning horizon. One way to achieve this and thus obtain a disaggregated master schedule is to simulate production runs using the following simple decision rule.

Set up and produce one product until the other product's inventory runs out. At that time set up the second product and run it until the first product's inventory runs out.

It should be clear that the simple rule above would not work for the general case with greater than two products. Procedures for disaggregation in such cases may be found in Elsayed and Boucher.

6.5 MATERIAL REQUIREMENTS PLANNING(MRP)

Overview and Problem Definition

MRP is a system of planning and scheduling the time phased material requirement for production operations.

By using the methods of aggregate production planning and subsequent disaggregation we can determine the weekly master schedule for end-products. The requirements of sub-assemblies, components, and raw stock items related to those end-products can be simply derived from the end-product demands.

The manufacturing routing sheets and product bills of materials describe the departmental routings and production times to manufacture the sub-assemblies and components.

Using these data bases in conjunction with a schedule of end-product requirements, it is possible to compute the timing of production for each component to meet the given end-product schedule. This, in effect, is the objective of a Material Requirements Planning (MRP) system. Thus, given a master schedule of end (or final) product, MRP computes the timing of all the sub-assembly, component and raw material production and purchasing activities required over the specified production horizon to meet the master schedule of the end-product. Moreover, it does so in such a way as to attempt to minimise work-in-process inventory.

Owing to the large amounts of data storage (a typical batch production facility may purchase/ produce 20,000 to 100,000 components) retrieval and computational requirements practical MRP systems have to be computerised.

MRP II (Manufacturing Resource Planning): It is an integrated information system used to plan and control inventories and capacities in manufacturing companies. Manufacturing Resource Planning system coordinates sales, purchasing, manufacturing, finance and engineering by adopting a focal production plan and by using one unified database to plan and update the activities in all the systems.

Parts Explosion Requirements

A particular product is generally composed of sub-assemblies and parts which in turn could be traced to items at the next level in a typical tree-like product structure. **The problems of finding the demand of all components, sub-assemblies for a given demand of the end-product is referred to as "Parts Explosion."** The problem could be complicated as a component or sub-assembly may be needed at different levels of the same or different end-products.

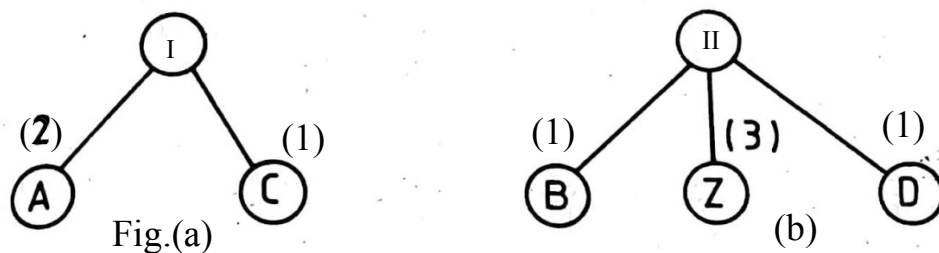
Suppose there are 2 end-products (I and II) which are assembled from 4 sub-assemblies (A, B, C, D) and 3 parts (X, Y, Z) as shown in the Fig. V The numbers in parentheses indicate the quantity of an item required.

First of all, we shall decide the level of an item. Put end-products I and II at level 0 (zero).

A and D are placed at level 1 since they are used directly for the assembly of end-products I and II of level 0 [Notice that B, X, Z, C, Y are all coming as the inputs of A (Fig. c), B (Fig. d), C (Fig. e) and D (Fig. f), but A and D are not coming and hence they are placed at level 1).

Next at level 2 who is to occupy ? Now out of B and C (sub-assemblies), we see that B takes Z and C as input (Fig. d) whereas C takes X and Y (Fig. e). Since B takes another sub-assembly C as its input, so B is kept at level 2.

Next level 3 will be occupied by remaining only sub-assembly C and part Z as they come direct input to product II. (See Fig. b). (Note: these sub-fig (a), (b), (c), (d), (e) and f) belong to Fig. V. (Done so only for explaining)



Two end products I and II

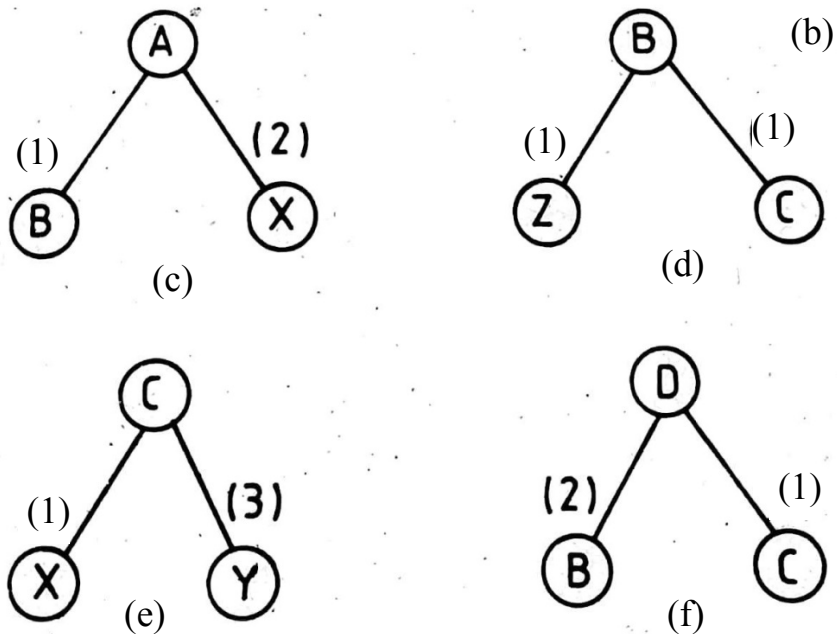


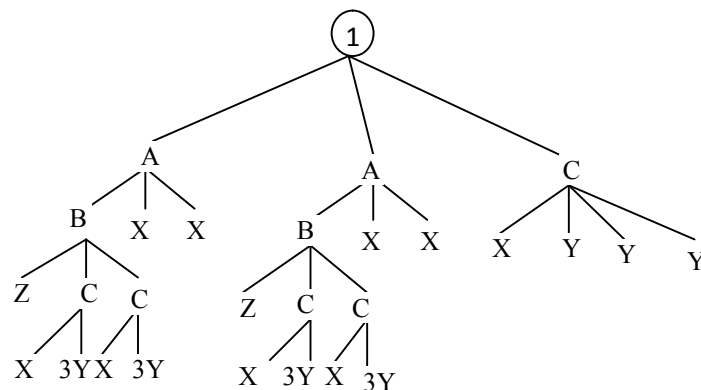
Figure V

The last slot of level 4 will be filled up by X and Y of course

Level 0 - $\begin{bmatrix} I \\ II \end{bmatrix}$
 Level 1 - $\begin{bmatrix} A \\ D \end{bmatrix}$
 Level 2 - B

Level 3 - $\begin{bmatrix} C \\ Z \end{bmatrix}$
 Level 4 - $\begin{bmatrix} X \\ Y \end{bmatrix}$

Parts Explosion Diagram for End-product I (Product Structure Tree)



Bill of Materials (BOM)

I = 1
 A = 2
 B = 2
 C = 5
 Z = 2
 X = 9
 Y = 15

Fig. VI

Total requirement for end-product I

Item →	1	11	A	D	B	C	Z	X	Y
Requirement →	1	-	2	—	2	5	2	9	15

Parts Explosion Diagram for End-Product II (Product Structure Tree)

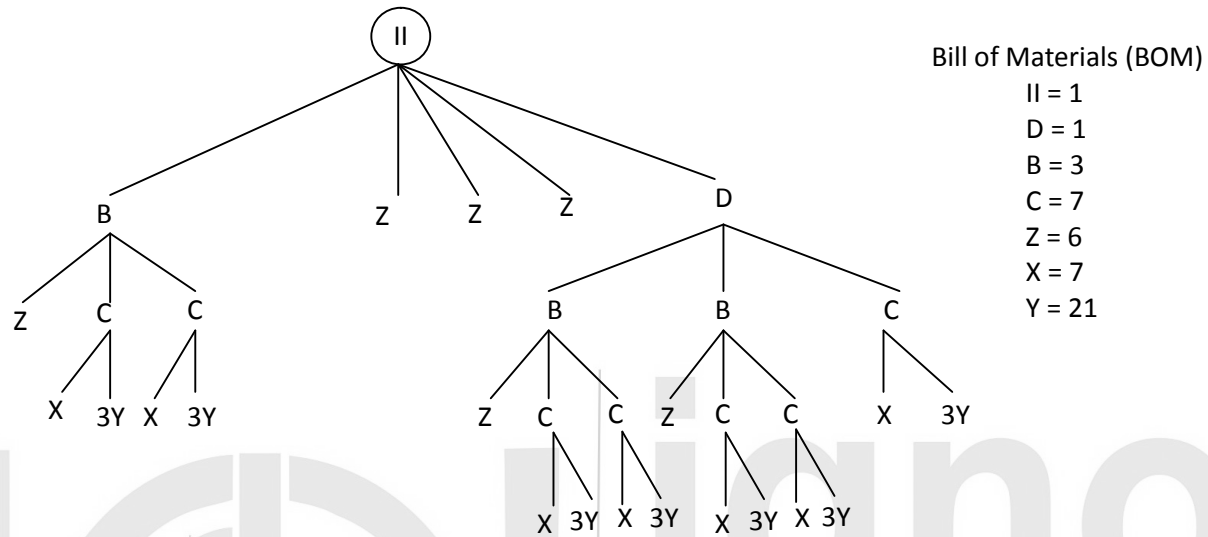


Fig. VII

Total Requirement for End-product II

Item →	I	II	A	D	B	C	Z	X	Y
Requirement →	—	1	—	1	3	7	6	7	21

Now for the End-Product I in quantity 20

The requirements are : $A = 2 \times 20 = 40$

$$D = 0$$

$$B = 2 \times 20 = 40$$

$$C = 5 \times 20 = 100$$

$$Z = 2 \times 20 = 40$$

$$X = 9 \times 20 = 180$$

$$Y = 15 \times 20 = 300$$

Similarly for 30 number of End-Product II, the corresponding requirements are:

$$\begin{aligned} A &= 0 \\ D &= 1 \times 30 = 30 \\ B &= 3 \times 30 = 90 \\ C &= 7 \times 30 = 210 \\ Z &= 6 \times 30 = 180 \\ X &= 7 \times 30 = 210 \\ Y &= 21 \times 30 = 630 \end{aligned}$$

The total requirement matrix R can be computed now and placed in a tabular form as below:

Table 6 Total Requirement Matrix R

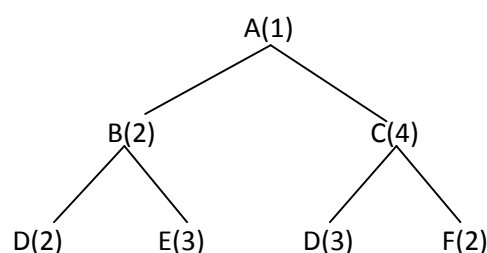
	I	II	A	D	B	C	Z	X	Y
I	1	-	2	-	2	5	2	9	15
II	-	1	-	1	2	7	6	7	21
A	-	-	1	-	1	2	1	4	6
D	-	-	-	1	2	5	2	5	15
B	-	-	-	-	1	2	1	2	6
C	-	-	-	-	-	1	-	1	3
Z	-	-	-	-	-	-	1	-	-
X	-	-	-	-	-	-	-	1	-
Y	-	-	-	-	-	-	-	-	1

This would be the basic information of how many of which components/sub-assemblies are required in order to meet the end-item demands. However this information has to be properly dovetailed with current inventory status, products lead time and the end-item demand schedule to be able to generate information on which components, sub-assemblies should be produced in a given period. This is the essence of the MRP system.

Example 6.4 One unit of product *A* is made-up of two units of *B* and four units of *C*. Again *B* is made of two units of *D* and three units of *E*. One unit of *C* is made-up of three units of *D* and two units of *F*.

- Draw a product structure tree.
- A, C, D, E* have lead time of 1 week and *B* and *F* have lead time of 2 weeks. If 100 units of *A* are required in week 5, develop the MRP specifying when items are to be ordered and received. There are no unit of inventory on hand.

Solution (a)



Bill of Materials (BOM)

$$\begin{aligned} A &= 1 \\ B &= 2 \\ C &= 4 \\ D &= 5 \\ E &= 3 \\ F &= 2 \end{aligned}$$

← WEEK →					
0	1	2	3	4	5
		200 B } 200 F } ordered LT = 2 weeks	400 C } 500 D } 300 E } ordered LT = 1 week	100 A ordered 200 B } 400 C } 500 D } 300 E } 200 F } Received	100 Received

Fig. VIII Product Structure Tree and Solution

Since (here is no unit of inventory on hand, gross requirement = net requirement).

MRP System in Practice

The major advantage of the MRP approach is its ability to plan discrete parts production for a very complex production system. MRP simply tries to schedule all the activities required to meet a given master schedule, while holding down work in process inventory.

Many commercially available MRP software packages provide a number of informative reports as shown in Figure IX.

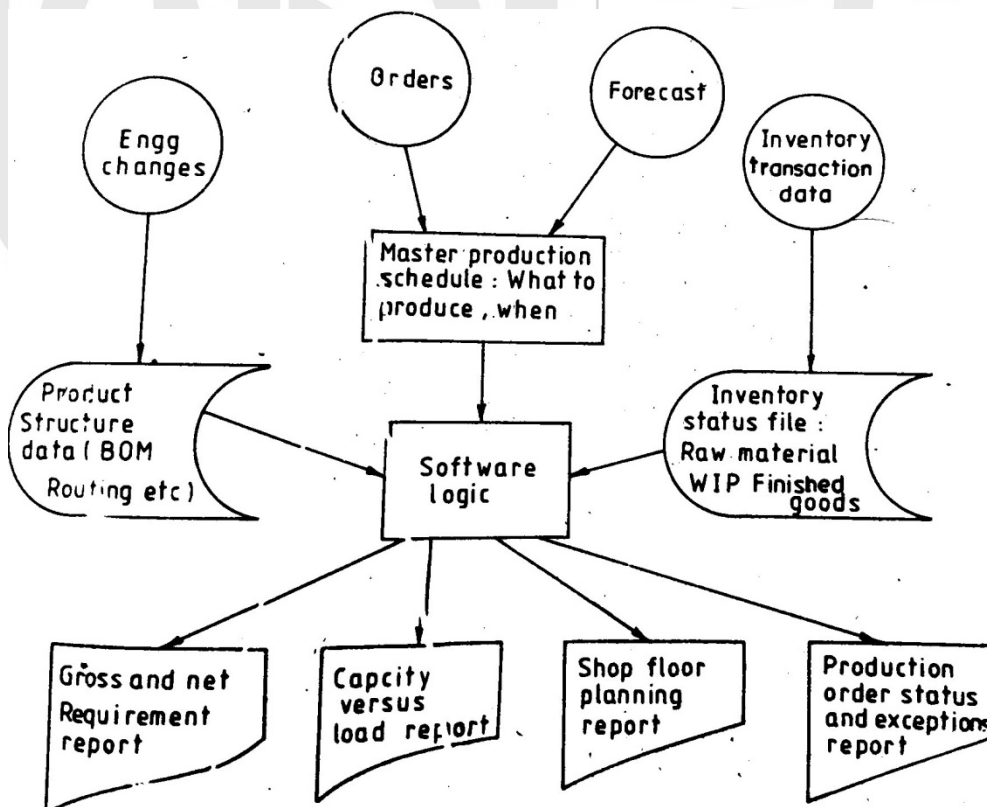


Figure IX : Typical Structure of an MRP Based Planning System

The major inputs to the system are.

- 1) The master production schedule specifying what to produce and when.

- 2) The product structure data including bill of materials, routing files with manufacturing/procurement lead times.
- 3) The inventory status file for raw material, work in process, and finished goods.

Among the outputs from the package, the “gross and net requirements report” indicates the timing of order releases required to meet the master schedule.

The “capacity versus load report” determines whether resources required by the work centres are available to produce these orders, which is useful in planning overtime/ sub-contracting.

The “shop floor planning report” is a listing of jobs by due date where the due date indicates when machining at that department should be completed in order to meet the schedule indicated by the gross and net requirements report. The shop floor supervisor will then release jobs to machines with completion time in hours and due dates for the items.

A typical commercial system provides additional information in the form of “Exception reports” indicating jobs to be expedited or de-expedited as a consequence of delays in production of components. De-expediting holds down work in process inventory.

In fact an MRP system has to be tailor made to the needs of the organisation, though most of the above features along with any special requirements are generally provided for.

6.6 THE LINE OF BALANCE (LOB) FOR PRODUCTION CONTROL AND MONITORING

The line of balance (LOB) technique developed by the U.S. army in the early 1950's is particularly suitable where co-ordination of demand upon resources to meet schedules and delivery commitments, is a problem. **In manufacturing business. LOB is a graphic aid that takes into account the essential factors of a schedule from procurement of raw materials to despatch of finished products.** The graphic technique of LOB is quite useful for the manufacturers of a batch of boilers, a batch of combat aircrafts and a batch of computers etc.

If a manufacturer commits supply of a certain number of products over a period of time, he has an option to complete all the parts in full and then commences assembly. This is advantageous from the point of processing costs but could mean major tie-up of capital. It is desirable when required for assembly, but at the same time, keep the inventories at the minimum. The problem then reduces to scheduling and control in such a way that balanced sets of parts are available, in the right amounts when required. The following example will explain the application of LOB clearly.

Example 6.5 (LOB) A company has received orders to deliver some finished items whose delivery schedule is given below :

Work number	0	1	2	3	4	5	6	7	8	9	10
Delivery of finished items required	0	12	14	8	6	10	12	14	16	18	20
Cumulative delivery	0	12	26	34	40	50	62	76	92	110	130

The product structure including the purchased parts, fabrication and assembly and the lead times of intermediate operations (items A and B are assembled first and then added to them is the item C to complete the finished product) are shown in the following operation programme. (Lead time is the latest possible completion time of the operation).

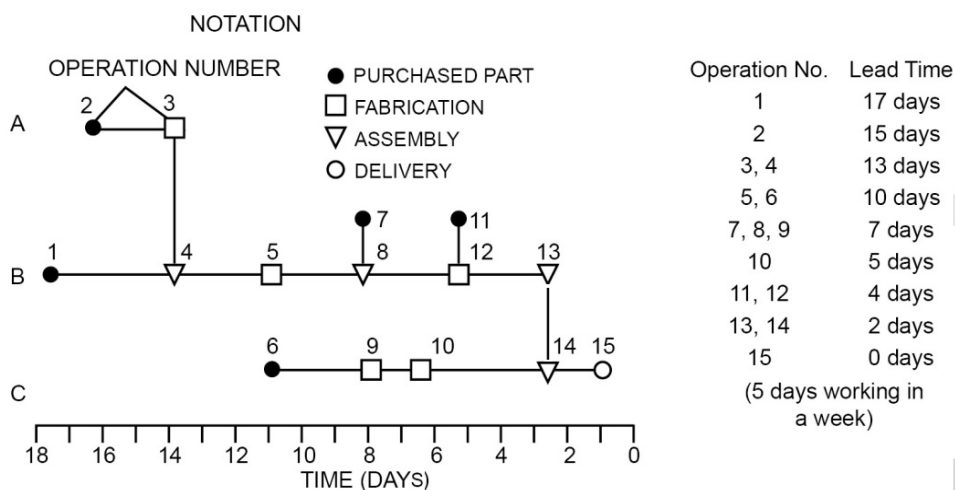


Fig. X Operation Programme

(For convenience the time scale runs from right to left and the final completion date is taken as zero).

After 4 weeks of production schedule, the number of units produced at each operation stage is shown in the table below:

Operation stage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Units of production	73	65	70	68	72	55	52	55	60	42	42	45	40	38	40

Develop LOB chart and show the details at the review date of week Number 4. (There is 5 days working in a week).

Solution. First draw the objective chart (LOB) taking week numbers in the X-axis and cumulative number of units in the Y-axis. Draw a vertical line at the week No. 4 indicating the progress review date. Taking LT of 17 days for operation 1 on the right of progress review date draw a vertical line to intersect the objective chart-LOB at point 'a'. From point 'a', draw a horizontal line to cut the cumulative No. of units line on the right approximately at 82 units which gives the "should have been" figure for operation 1 i.e. LOB for the operation 1. Similarly for the lead time of 15 days for operation 2 which gives a LOB mark of approximately 76 units for

operation 2. Likewise the LOB marks can be had from operation 3 to operation 15 in a similar fashion (see Fig. XI)

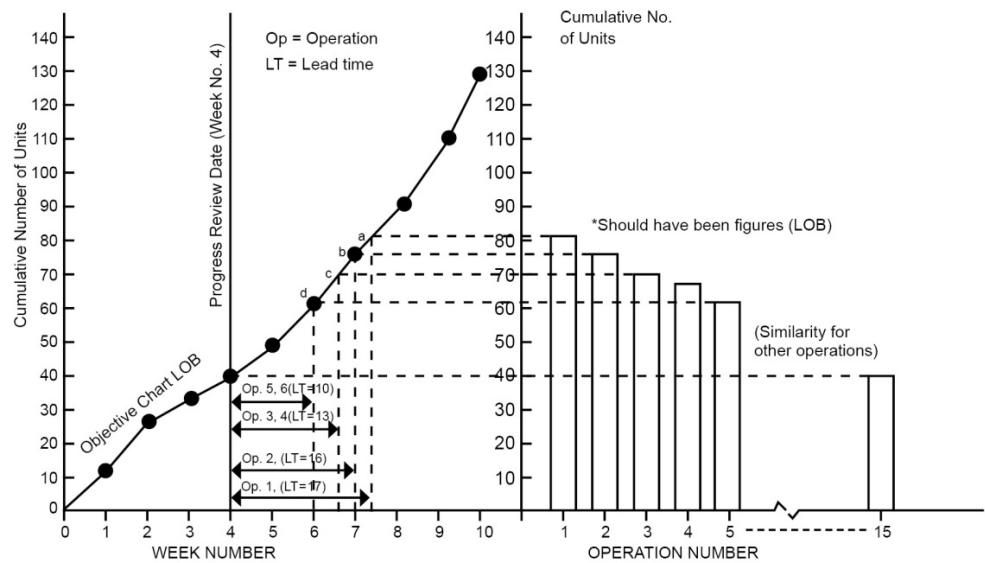


Fig. XI Construction of LOB

Now the programme progress chart (as at week no. 4) can be drawn to compare the actual progress with the scheduled or planned progress, i.e., with the "should have been" figures. The figures for the actual progress can be collected from the actual state of affairs prevailing in the system at the progress review date (at week no. 4). A histogram is made with the help of these data (as at week no. 4). Analysis of progress is finally done to identify shortages and pinpoint the specific operations non-conforming to the schedule. For instance, in Fig. XII the requisite number of completed items have been delivered to the customer (operation 15 = 40), but both operations 13 and 14 are in short supply and unless deliveries during the next week are expedited, shortages may occur. Similarly for operations 1, 2, 4, 6, ...etc.

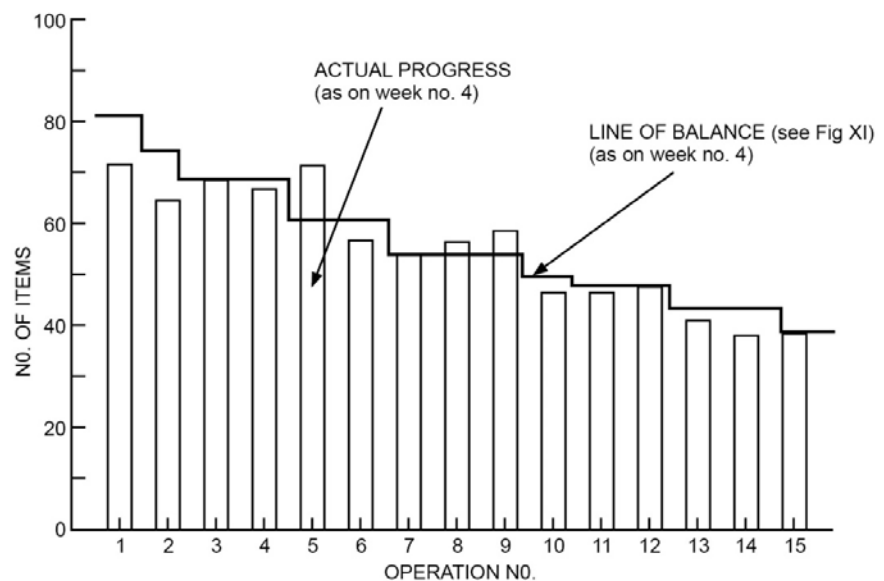


Fig. XII Programme Progress Chart (as at week no. 4).

Besides providing information as to whether the production is low or the inventories are high in certain key areas, the line of balance (LOB) also gives diagnostic information. LOB technique is an example of management by exception (MBE) since it deals only with the important or crucial operations in a job, establishes a schedule or plan for them and attracts attention to those that do not confirm to this schedule.

6.7 PROBLEMS AND PROSPECTS OF BATCH PRODUCTION

In batch production systems the in-process inventories and the lead times tend to be large. As we have seen MRP is a vehicle to control the discrete parts production planning and also to reduce work in-process inventory. However, the drawback of MRP is that it is expensive to implement as it requires the capability of a mainframe computer, technical support professionals, and MRP software. Instead of designing production control tools for a complex production system, attempts have been made to simplify the system itself. One example of this is Kanban developed in Japan and being implemented at Takahama plant of Toyota. Kanban emphasises the reduction in production lead time and in-process inventory by specifying shorter production runs of any single product. Kanban is characterised by quick change tooling to reduce set up times. Production control is decentralised. Production activity is regulated by Kanban cards. Conflicts are handled by management and supervisory intervention on the shop floor. Further details of Kanban may be found in Elsayed and Boucher.

Another major development with respect to the complicated problems of batch manufacturing has been the development of Flexible Manufacturing Systems (FMS) in an attempt to apply computer controls to production scheduling, the control of machines and the movement of materials in a discrete parts manufacturing environment.

FMS may be defined as general purpose manufacturing machines, which are quite versatile and capable of performing different types of operations, linked together by material handling systems. Both the machines and the material handling systems are under the control of a central computer system. There are two main objectives of employing FMS:

- i) to permit machining of any desired mix of parts in a given time period, and
- ii) to reduce the work in process and increase machine utilisation in small-lot manufacture.

6.8 SUMMARY

In this unit we have presented the features of batch production systems. Normally we resort to batch production of products when there is a continuous demand for products and the production rates exceed the rates of demand. Continuous

production would obviously lead to ever increasing inventory build-ups in such cases.

The problems of finding the batch size in both the single product and the multiproduct situation (with the same manufacturing facility) have been considered. Essentially, the approach is to, balance two conflicting costs: the cost of set up and the inventory carrying cost, where the former tends to decrease while the latter increases with larger batch sizes.

Aggregate production planning to economically meet a demand schedule over a planning horizon (of say a few months to a year) has been discussed and illustrated through a small example. Disaggregation to obtain the master schedule is also indicated.

A problem, once the master schedule is obtained, is to plan for procurement and production of various components and sub-assemblies in time—this is done through Material Requirements Planning (MRP). How to obtain the demand for parts has been illustrated in parts explosion. Subsequently, the structure of a practical MRP system and the various reports that may be generated are highlighted.

The LOB technique for production monitoring has been discussed next, pointing out the usefulness of this management by exception tool for production managers.

Finally, some developments in areas of discrete parts manufacturing have been indicated with a brief discussion of Kanban and Flexible Manufacturing Systems.

6.9 KEY WORDS

Aggregate Production Planning: Allocation of work force size and production level to meet the forecasted demands of goods and services over the planning horizon. This is generally done in terms of an aggregate product representing the combined needs of the various products.

Batch Production: A production situation where production takes place in lots or batches as opposed to continuous production. Justified when rate of production exceeds the rate of demand. Determination of batch sizes and sequencing or scheduling of batches in multiple product situation are the key decisions in batch production.

Line of Balance (LOB): A production control device effective in batch production to compare progress on each operation with the progress necessary to satisfy the eventual delivery requirements (not to be confused with line balancing used for designing assembly lines in mass production).

Master Schedule,. A detailed product by product production plan showing the quantities of each product to be produced in each period of the planning horizon.

Material Requirements Planning (MRP): This is generally a computer-based system for drawing up detailed production/procurement schedules for various parts, sub-assemblies needed to meet a given master schedule of the end item. It utilises the product structure, processing, information like production/procurement leadtimes and inventory status in a bid to produce the best plan.

Parts Explosion: A particular product is generally composed of sub-assemblies and parts which in turn could be traced to items at the next level in a typical tree-like product structure. The problem of finding the demand of all components, sub-assemblies for a given demand of the end product is referred to as ‘Parts Explosion’. The problem could be complicated as a component or sub-assembly may be needed at different levels of the same or different end-products.

6.10 SELF-ASSESSMENT EXERCISES

- 1) Distinguish between mass and batch production, under what conditions is batch production justified?
- 2) A product may be made in the plant or purchased from an outside vendor. The inventory carrying cost per unit is Rs. 5 per day and no shortages are to be allowed. Given the information in the following table, what is the best policy for an annual demand of (a) 30,000 units and (b) 20,000 units.

	In-plant	Vendor
Production per day(units)	200	8
Lead time(days)	4	9
Cost per units (Rs)	500	540
Order cost(Rs.)	1000	700

[Ans:- Take 1yr=240 working days. (a) Total cost- In-plant Rs 1,51,64,317 < Vendor 1,64,24,500 (b) Total cost- In-plant Rs 1,01,67,332 < Vendor 1,09,83,303 In both the cases- Go for In-plant Production]

- 3) A company is to produce three products on the same machine using a common cycle policy. What should be the respective batch sizes and the total annual cost given the following data?

	Product 1	Product 2	Product 3
Production per year (units)	6000	12000	4500
Demand per year(units)	2000	3000	1500
Setup cost	Rs. 500	Rs. 400	Rs. 600
Inventory Carrying cost per unit per year	Rs. 400	Rs. 700	Rs. 300

[Ans- $Q_1^0 = 70.58$, $Q_2^0 = 105.87$, $Q_3^0 = 52.94$, $TC = \text{Rs. } 2,12,501$]

6.11 FURTHER READINGS

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UNIT 7 PLANNING AND CONTROL FOR JOB SHOP PRODUCTION

Objectives

After completion of this unit, you should be able to:

- understand the nature of job production, appreciate the variety of problems that may arise in job shops and sequence a number of jobs in a static job shop with a single machine to accomplish a number of objectives
- sequence a number of jobs in a static two-machine flow shop to minimise the total completion time, develop a schedule to minimise time of completion (graphically) of two jobs requiring processing on a number of machines in any specified order and become aware of the use of different priority despatching rules in practical job shops.

Structure

- 7.1 Introduction
- 7.2 Variety of Problems in Job Production
- 7.3 n Jobs One Machine Case
- 7.4 n Jobs Two Machines Case
- 7.5 Two Jobs m Machines Case
- 7.6 Scheduling Rules for Job Shops (Job Shop Scheduling)
- 7.7 Problems and Prospects of Job Production
- 7.8 Summary
- 7.9 Key Words
- 7.10 Self-assessment Exercises
- 7.11 Further Readings

7.1 INTRODUCTION

Unlike mass production systems where a limited number of items are produced continuously without any changes, the job shop characterises a situation where a variety of jobs is handled, each job being different from the previous one. Job shops differ from batch production in the following manner. In batch production there is generally a continuous demand for products but owing to a higher rate of production as compared to the rate of demand, production is undertaken, in batches. Thus batch production caters to a predictable variety of jobs. In the job shop, however, both the nature and demand of jobs is unpredictable. Moreover, each order or job is unique, requiring its own makeup of operations and times for processing through a number of machines or facilities in a factory.

A job shop typically consists of general purpose machines clubbed into different departments. Each job, governed by its unique technological requirements, demands processing on machines in a certain order. Because of the variety of tasks, the job shop becomes a complex queueing system: a job leaves one machine and proceeds on its route to another for the next operation, only to find other jobs already waiting for the machine to complete its current task, so that a queue of jobs in front of that machine is formed; alternatively, a machine may finish its task and be ready to take the next job, but no jobs are available, so that the machine becomes idle. Planning for the job shop essentially involves deciding the order or priority for jobs waiting to be processed at each machine to achieve the desired objectives.

7.2 VARIETY OF PROBLEMS IN JOB PRODUCTION

A typical formulation of the job shop scheduling problem is: given n jobs to be processed through m machines, each job having a predetermined sequence of operations and processing times, in what order should the jobs be loaded on the machines so as to optimise certain performance criterion?

A typical list of performance criteria to be optimised is:

- 1) Total processing time or makespan
- 2) Mean flow time (or mean time in the job shop)
- 3) Idle time of machines
- 4) Mean lateness of jobs (lateness of a job is defined as the difference between the actual completion time of the job and its due date)
- 5) Mean earliness of job (if a job is completed before its due date, then its lateness value is negative and it is referred to as earliness instead)
- 6) Mean tardiness of jobs (if a job is completed after its due date, then its lateness value is positive, and it is referred to as tardiness instead)
- 7) Number of tardy jobs
- 8) Mean queue time
- 9) Mean number of jobs in the system.

Moreover the solution procedure depends on the following factors:

- 1) The number of jobs to be scheduled
- 2) The number of machines in the machine shop
- 3) Type of manufacturing facility (flow shop or job shop)
- 4) Manner in which jobs arrive at the facility (static or dynamic)
- 5) Criterion by which scheduling alternatives are to be evaluated

If the number of jobs (n) and the number of machines (m) increase, the scheduling problem becomes more complex. In fact, no exact or optimal solutions exist for sequencing problems with large n and m . Simulation and heuristic algorithms seem to be the solution techniques for real life scheduling problems.

We initiate the discussion on job shops with some very simple one machine and two machine cases for which exact solutions exist. Many practical situations would fit into these categories as you would see. Next, a graphical procedure for scheduling of 2 jobs to minimise the total time of processing is proposed. And, finally, some scheduling rules (Priority Dispatching Rules for sequencing jobs) and results from simulation studies are presented.

7.3 **n JOBS ONE MACHINE CASE**

The case when a number of jobs is to be processed on a single facility occurs quite often in practice such as a number of cars to be serviced at a service station, number of patients to be treated by a doctor, number of job requests from different terminal users to be executed by a computer, a number of different jobs to be machined on a lathe, or a number of broken down machines to be repaired by a service mechanic.

In all such cases, we, as human beings, are used to the first come first served concept. This seems to be the almost universally accepted code for handling queues at milk booths, post-offices, banks and almost anywhere we go. Perhaps the validity of this rule stems from the democratic notion that all individuals are equally important and it is 'just' or 'proper' to assign priorities on early arrivals. In fact we all know how unpleasant scenes and heart-burnings can result in real life if this chosen rule is violated, for instance, when a newcomer tries to enter a queue at a vantage position or a senior is superseded in a job promotion.

We shall see that if the objective is not to give a sense of satisfaction and justice to waiting jobs (when, for instance, the jobs lack the human attributes of ego and pride) it is possible to consider a number of other rules which would yield more favourable results in terms of objectives like 'the mean flow time, average in-process inventory of jobs, the mean lateness, mean waiting time of jobs, the number of tardy jobs and the total processing time of jobs. It is in this framework that the following scheduling rules should be considered:

We shall consider a static job shop in which a number of jobs, n , with known processing times require processing on a single machine. The job shop is static in that new job arrivals do not disturb the processing of these n jobs. It may be assumed that new job arrivals wait for being considered in the next batch of jobs after the processing of the current n jobs is accomplished.

The following definitions are in order:

n = number of jobs

t_i = processing time of job i

W_i = waiting time before processing for job i

F_i = flow time of job $i = W_i + t_i$

C_i = completion time of job i

d_i = due date of job i

L_i = lateness of job $i = C_i - d_i$

E_i = earliness of job $i = \max(0, -L_i)$

T_i = tardiness of job $i = \max(0, L_i)$

N_T = number of tardy jobs

Since the total time to complete the jobs (makespan, as it is often called) is fixed and equal to sum of processing times for all jobs in all possible sequences in this n machine one job case, other optimality criteria, e.g. minimising the mean flow time or some function of lateness of jobs is resorted to.

Shortest Processing Time (SPT) Rule

Sequencing the jobs in a way that the job with least processing time is picked up first followed by the one with the next smallest processing time and so on is referred to as SPT sequencing and achieves the following objectives simultaneously:

- (i) minimising mean lateness
- (ii) minimising mean lateness time
- (iii) minimising mean waiting time
- (iv) minimising the mean number of tasks waiting as in-process inventory.

A variation of the SPT rule is the weighted-scheduling rule (WSPT) which is used when the importance of the tasks vary. A weight w_i is assigned to each job, a larger value indicating greater importance. Then, by dividing the processing time by the weighting factor the tendency is to move the more important task to an earlier position in the sequence. The weighted mean flow time is given by:

$$WMFT = \frac{\sum_{i=1}^n w_i F_i}{\sum_{i=1}^n w_i}$$

The WSPT rule for minimising weighted mean flow time sequences the n jobs such that

$$\frac{t[1]}{w[1]} \leq \frac{t[2]}{w[2]} \leq \dots \leq \frac{t[n]}{w[n]}$$

where the number in square brackets defines the position of the job in the optimal sequence.

The Proofs of the preceding statements concerning SPT and WSPT are available in different literatures (see for instance, Baker). We shall only illustrate the application of these rules to an example problem.

Example 7.1

Consider the 8 jobs with processing times, due dates and importance weights as shown below.

Table 1: Data for eight job one Machine Example

Job i	1	2	3	4	5	6	7	8
Processing time (t_i)	5	8	6	3	10	14	7	3
Due date (d_i)	15	10	15	25	20	40	45	50
Importance weight (w_i)	1	2	3	1	2	3	2	1
t_i/w_i	5.0	4.0	2.0	3.0	5.0	4.7	3.5	3.0

A) Shortest Processing Time (SPT) Rule : Here the job with the least processing time is picked up first, followed by the one with the next smallest time and so on till we have picked up all the jobs. SPT sequencing achieves the following objectives

- i) minimizing mean flow time
- ii) minimizing mean in-process inventory
- iii) minimizing mean waiting time
- iv) minimizing mean lateness.

[FCFS (first come first served) Rule is as the jobs are in given order, i.e., 1-2-3-4-5-6-7-8 or A-B-C-D.... etc.]

Now arranging the jobs with their processing time in the ascending order, we get

Job	4	8	1	3	7	2	5	6
Processing time	3	3	5	6	7	8	10	14
Importance wt. (w_i)	1	1	1	3	2	2	2	3

The SPT sequence is 4-8-1-3-7-2-5-6 resulting in completion of these jobs at times 3,6,11,17,24,32,42 and 56 respectively. (For tie, we may take any sequence. For example if t_i , for job 4 = 3, for job 8 = 3 then we may take first job 4 and then job 8 or the reverse).

The mean flow time = $= \frac{3+6+11+\dots+56}{8} = \frac{191}{8} = 23.875 \text{ units} = 23.9 \text{ units}$
(See Fig.I)

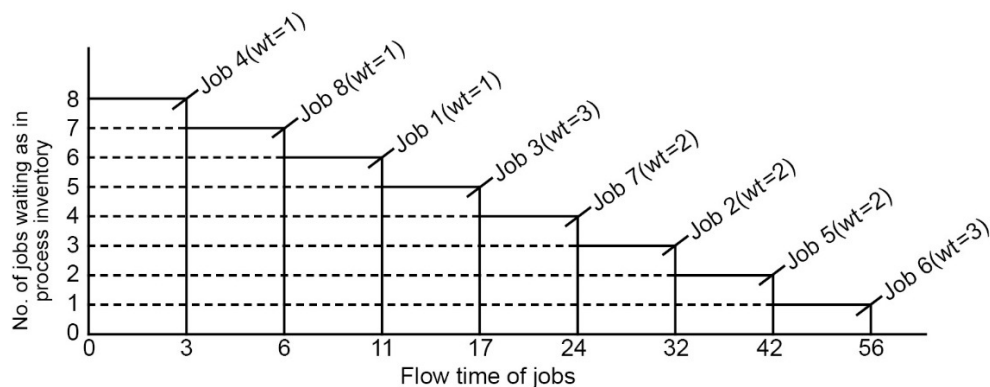


Figure I: Flow time of jobs

8 no. of tasks waiting as in-process inventory during time 0-3 (see graph above)

7 no. of tasks waiting during 3-6

6 no. of tasks waiting during 6-11

5 no. of tasks waiting during 11-17

4 no. of tasks waiting during 17-24

3 no. of tasks waiting during 24-32

2 no. of tasks waiting during 32-42

1 no. of tasks waiting during 42-56

Weighted mean flow time

$$= \frac{1 \times 3 + 1 \times 6 + 1 \times 11 + 3 \times 17 + 2 \times 24 + 2 \times 32 + 2 \times 42 + 3 \times 56}{1 + 1 + 1 + 3 + 2 + 2 + 2 + 3}$$

$$= \frac{435}{15} = 29$$

Thus the average in process inventory (total flow times of jobs = 56)

$$= \frac{(8 \times 3) + (7 \times 3) + (6 \times 5) + (5 \times 6) + (4 \times 7) + (3 \times 8) + (2 \times 10) + (1 \times 14)}{\text{jobs}} = 3.41$$

Waiting time for each job:

Job	number	4	—	waiting	time	=	0
Job	number	8	—	waiting	time	=	3
Job	number	1	—	waiting	time	=	6
Job	number	3	—	waiting	time	=	11

Job	number	7	—	waiting	time		17
Job	number	2	—	waiting	time	=	24
Job	number	5	—	waiting	time	=	32
Job	number	6	—	waiting	time	=	42
Total							= 135

$$\text{Mean waiting time under SPT rule} = \frac{135}{8} = 16.875 \text{ units.}$$

Lateness of each job. Job no. 4. lateness = Completion time of job i - due date of job ,

$$\text{Job no. 4 lateness} = 3 - 25 = -22$$

$$\text{Job no. 8. lateness} = 6 - 50 = -44$$

$$\text{Job no. 1. lateness} = 11 - 15 = -4$$

$$\text{Job no. 3, lateness} = 17 - 15 = +2$$

$$\text{Job no. 7, lateness} = 24 - 45 = -21$$

$$\text{Job no. 2, lateness} = 32 - 10 = +22$$

$$\text{Job no. 5, lateness} = 42 - 20 = +22$$

$$\text{Job no. 6, lateness} = 56 - 40 = +16$$

(Positive lateness is tardiness)

$$\text{Mean lateness} = \frac{-22-44-4+2-21+22+22+16}{8} = -\frac{29}{8} = -3.625 \text{ units.}$$

$$\text{Mean tardiness} = \frac{0+0+0+2+0+22+22+16}{8} = \frac{62}{8} = 7.8$$

(We have taken into account only tardy jobs)

No. of tasks actually late = 4 (Job no. 3, 2, 5, 6) = No. of tardy jobs.

Maximum lateness = 22 units (Job 5 and job 2 each)

B) Weighted Shortest Processing Time (WSPT) Rule: If the importance weights w_i are to be considered WSPT rule could be used to minimise the weighted mean flow time to yield the sequence 3-4-8-7-2-6-1-5 (shown below how).

Table 2

Task (i)	Processing time (t_i)	Importance wt (w_i)	t_i/w_i
1	5	1	5/1=5 (VII)
2	8	2	8/2 = 4 (V)
3	6	3	6/3 = 2 (I)
4	3	1	3/1 = 3 (II)
5	10	2	10/2 = 5 (VIII)
6	14	3	14/3 = 4.7 (VI)
7	7	2	7/2 = 3.5 (IV)
8	3	1	3/1=3 (III)

The resulting sequence is 3 – 4 – 8 – 7 – 2 – 6 – 1 – 5.

The respective flow time of jobs in this sequence are 6, 9 (= 6 + 3), 12 (= 9 + 3), 19 (= 12 + 7), 27 (= 19 + 8), 41 (= 27 + 14), 46 (= 41 + 5), 56 (= 46 + 10)

$$\text{Mean flow time} = \frac{6 + 9 + 12 + 19 + 27 + 41 + 46 + 56}{8} = \frac{216}{8} = 27 \text{ units}$$

Weighted mean time flow

$$= \frac{(3 \times 6) + (1 \times 9) + (1 \times 12) + (2 \times 19) + (2 \times 27) + (3 \times 41) + (1 \times 46) + (2 \times 56)}{3 + 1 + 1 + 2 + 2 + 3 + 1 + 2}$$

$$= \frac{412}{15} = 27.47 \text{ units} \approx 27.5 \text{ units}$$

Similarly we can calculate the following:

Mean lateness = -0.5

Mean tardiness = 10.6

No. of tardy jobs = 4 (job no. 2, 6, 1, 5)

Maximum tardiness = 36 units

C) Earliest Due Dates (EDD) Rule : Here the jobs are sequenced in the order of non-decreasing due dates of jobs. The EDD sequence is 2(10 units of time), - 1(15 units) - 3(15 units) - 5(20 units) - 4(25 units) - 6(40 units) - 7(45 units) - 8(50 units). The sequence 2-1-3-5-4-6-7-8 yields the completion time of these job as 8, 13 (=8 + 5), 19 (=13 + 6), 29 (=19 + 10), 32 (=29 + 3), 46 (=32 + 14), 53 (=46 + 7), 56 (=53 + 3). The respective lateness value = -2 (=8 - 10), -2 (=13 - 15), +4 (=19 - 15), +9 (29 - 20), +7 (=32 - 25), +6 (=46 - 40), + 8 (=53 - 45), + 6 (56 - 50). Mean flow time = 32 and weighted mean flow time = 31.7.

$$\text{Mean lateness} = \frac{-2 - 2 + 4 + 9 + 7 + 6 + 8 + 6}{8} = \frac{36}{8} = +4.5 \text{ units.}$$

$$\text{Mean tardiness} = \frac{0 + 0 + 4 + 9 + 7 + 6 + 8 + 6}{8} = \frac{40}{8} = +5 \text{ units.}$$

Maximum lateness = 9 units compared to 22 in SPT.

No. of late jobs = 6 (Job No. 3, 5, 4, 6, 7, 8) = No. of tardy jobs.

The objective of EDD rule is (i) to minimise the maximum job lateness. Unfortunately EDD rule tends to make more tardy jobs and at times increases the mean tardiness.

D) Hodgson's Algorithm : Suppose there is a penalty cost associated with a job in case it was tardy no matter how tardy it was. In this situation, naturally one would like to minimize the number of tardy jobs. The EDD rule gives the desired schedule only if it results in zero number of tardy jobs (i.e., no tardy job) or one tardy job. If more than one tardy job

results, the following algorithm due to Hodgson will yield the desired objective.

Step 1. Order all tasks by the EDD rule, if zero or one task is tardy (positive lateness), then stop, otherwise go to step (2) if more jobs are tardy..

Step 2. Starting at the beginning of the EDD sequence and working towards the end, identify the first tardy task. If no further tasks are tardy, go to step (4) otherwise go to step (3).

Step 3. Suppose that the tardy task is in the i th position in the sequence. Examine the first i task in the sequence and identify the one with the longest processing time. Remove the task and set it aside. Revise the completion time of other task to reflect this removal and return to step (2). [See the treatment in the Example below to understand the statement clearly.].

Step 4. Place all those tasks that were set aside in any order at the end of the sequence.

As per EDD rule the sequence is 2–1–3–5–4–6–7–8 with 6 tardy jobs which is more than 1 job. So we move to steps (2) and (3) as shown below:

Task (i)	2	1	3	5	4	6	7	8
Processing time (t_i)	8	5	6	10	3	14	7	3
Completion time (C_i):	8	13	19	29	32	46	53	56
Due date (d_i)	10	15	15	20	25	40	45	50
Lateness $L_i = C_i - d_i$	-2	-2	+4	+9	+7	+6	+8	+6

Examining it, we find that task 3 (in the sequence) is the 1st tardy task and it is in the 3rd position (i th position = 3rd position) of the sequence. Now examine the first 3 tasks (i.e., i tasks) in the sequence and identify the one with the longest processing time. Obviously out of the first 3 tasks (tasks 2, 1 and 3), task 2 has the longest processing time of 8 units, so remove this task and set it aside and the resultant table is shown below:

i	1	3	5	4	6	7	8
t_i	5	6	10	3	14	7	3
C_i	5	11	21	24	38	45	48
d_i	15	15	20	25	40	45	50
L_i	-10	-4	+1	-1	-2	0	-2

Examining the above table once again, we find that the 1st tardy task is task 5 which lies in the 3rd position (i th position = 3rd position). So looking at the first 3 tasks (i tasks) in the resultant sequence we find task 5 has the longest processing time of 10 units. Hence it is removed and the resultant table is :

Task i	1	3	4	6	7	8
t_i	5	6	3	14	7	3
C_i	5	11	14	28	35	38
d_i	15	15	25	40	45	50
L_i	-10	-4	-1	-12	-10	-12

Now no more task is tardy.

Now the revised order is 1-3-4-6-7-8 and the last part consists of task 2 and task 5 in ANY ORDER. Arranging them in SPT order, 2 (=8 units of t_i) and then 5 (=10 units of t_i) we get the complete sequence as 1-3-4-6-7-8-2-5. We have L_i of the last two tasks as

i	2	5
t_i	8	10
C_i	46	56
d_i	10	20
L_i	+36	+36

So, two tasks 2 and 5 are now late. The lateness values are -10, -4, -11, -12, -10, -12, +36, +36

$$\text{Mean lateness} = \frac{-10 - 4 - \dots + 36 + 36}{8} = 1.625$$

$$\text{Mean tardiness} = \frac{0 + 0 + \dots + 36 + 36}{8} = 9$$

Maximum lateness = 36 units (both jobs 2 and 5)

No. of tardy jobs = 2 (job 2 and job 5)

The objective of Hodgson's Algorithm is to minimise the number of tardy jobs.

E) Slack Rule : If there is a penalty for all tardy tasks and the quantum of penalty varies with the magnitude of tardiness (greater penalty for greater tardiness), then obviously our attempt will be to minimise the mean tardiness. As there is no simple scheduling rule even for n jobs on 1 machine to reduce the mean tardiness, Baker has shown that in the following simple situation, the EDD and SPT rules also minimize the mean tardiness.

- 1) If the EDD rule produces zero or one tardy job, then it minimises mean tardiness.
- 2) If all tasks have the same due date or if the SPT rule results in all tasks being tardy, then the SPT rule minimises mean tardiness.

A heuristic rule (simple rule with no proof) that tends to minimize mean tardiness is the shortest SLACK time rule. This rule does not

necessarily give optimum results, but it gives good solution in practical cases. Slack time = due date of the job - its processing time.

Now the slack times for our problem are calculated below :

i	1	2	3	4	5	6	7	8
t_i	5	8	6	3	10	14	7	3
d_i	15	10	15	25	20	40	45	50
Slack time	10	2	9	22	10	26	38	47

Taking the slack times in the ascending order, the sequence is 2-3-1-5-4-6-7-8 which yields completion times of 8, 14, 19, 29, 32, 46, 53 and 56 and the tardiness values are 0, 0, 4, 9, 7, 6, 8, 6 respectively.

$$\text{Mean tardiness} = \frac{0 + 0 + 4 + \dots + 8 + 6}{8} = 5.0 \text{ units}$$

Mean flow time calculated out to be = 32.1 units

Weighted mean flow time = 31.1 units.

Table 3. Comparison of Five Scheduling Rules Rule

Rule	Objective (to minimize)	Mean flow time	Weighted mean	Mean lateness flow time	Maximum tardiness	No. of tardy jobs	Mean tardiness
SPT	(i) mean flow time (ii) mean in-process inventory (iii) mean waiting time (iv) mean lateness	23.9	29.0	-3.6	22	4	7.8
WSPT	Weighted mean flow time	27.0	27.5	-0.5	36	4	10.6
EDD	Maximum job lateness	32.0	31.7	4.5	9	6	5.0
Hodgson	Number of tardy jobs	29.1	29.9	1.6	36	2	9.0
Slack	Mean tardiness (heuristic)	32.1	31.1	4.6	9	6	5.0

Yet another priority dispatching rule oftenly used is the **Critical Ratio Rule** which is briefly discussed below:

$$\text{Critical Ratio Rule: Critical Ratio} = \frac{\text{Time remaning for the date of the job}}{\text{Time needed to complete the job}}$$

With eference to the example 7.1, we have the following-

for job 1 i.e.

$$J_1, CR = \frac{15-5}{2} = 2, \text{ for } J_2 = 0.25, \text{ for } J_3 = 1.5, \text{ for } J_4 = 7, \text{ for } J_5 = 1, \text{ for } J_6 = 1.86,$$

$$\text{for } J_7 = 5.43, \text{ for } J_8 = 15.67$$

The sequence of jobs as per increasing degere of ratios under Critical Ratio Rule is

2 - 5 - 3 - 6 - 1 - 7 - 4 - 8.

7.4 n JOBS TWO MACHINES CASE

Consider the situation where n jobs must be processed by two machines, ' followed by M2. The processing times of all jobs on M1 and M2 are known and deterministic. It is required to find the sequence which minimises the time to complete all jobs.

Johnson developed an algorithm that can be used to obtain an optimal sequence in such a case. Johnson's algorithm is summarised below:

- 1) List all processing times of all jobs on machine M1 and M2.
- 2) Scan through all processing times for all jobs. Locate the minimum processing time.
- 3) If the minimum processing time is on M1, place the corresponding job first (as early as possible) in the sequence. If it is on M2, place the corresponding job last (as late as possible) in the sequence.
- 4) Eliminate the assigned jobs (already placed in the sequence as a result of step 3) and repeat steps 2 and 3 until all jobs are sequenced.

Any ties in processing times while applying step 3 are broken arbitrarily because they cannot affect the minimum elapsed time to complete all jobs.

Under certain restrictive assumptions, Johnson's Rule may be extended to n job 3 machine or more flow shop situation. The interested reader may refer to any of the references, Baker or Elsayed and Boucher for details.

Example 7.2. Six jobs go first on machine 1 and then over 2. The order of the completion the jobs has no significance. The following table gives the machine times in hours for six jobs on the two machines:

Job No (i)	1	2	3	4	5	6
Time of machine 1 (A_i)	5	9	4	7	8	6
Time of machine 2 (B_i)	7	4	8	3	9	5

Find the sequence of the jobs that minimises the total elapsed time to complete the jobs. Find the minimise time of completion of all the jobs by using Gantt chart or by other method.

Solution. Out of $A_1, A_2, A_3, A_4, A_5, A_6$ and $B_1, B_2, B_3, B_4, B_5, B_6$, the smallest time is B_4 (i.e. time for job 4 on machine 2). Therefore we shall do the job 4 in the last and list the element as follows:

					1
					4

(1 denotes the order of choice)

Now of the remaining jobs

i : 1 2 3 5 6
A_i : 5 9 4 8 6
B_i : 7 4 8 9 5

Minimum (A_i, B_i) = A₃ = B₂ = 4 : Job A₃ to be done on 1 and job B₂ goes to next to last job B₄ on machine 1.

II				II	I
3				2	4

Now the remaining jobs

i : 1 5 6
A_i : 5 8 6
B_i : 7 9 5

Minimum (A_i, B_i) = A₁ = B₆ = 5 : Job 1 to m/c 1 next to job 3 and job 6 to m/c 1 next to job 2.

II	III	IV	III	II	I
3	1		6	2	4

Now only one space is left vacant above and it is to be filled obviously by job 5. That completes the sequence as below–

II	III	IV	III	II	I
3	1	5	6	2	4

Now to calculate minimum elapsed time

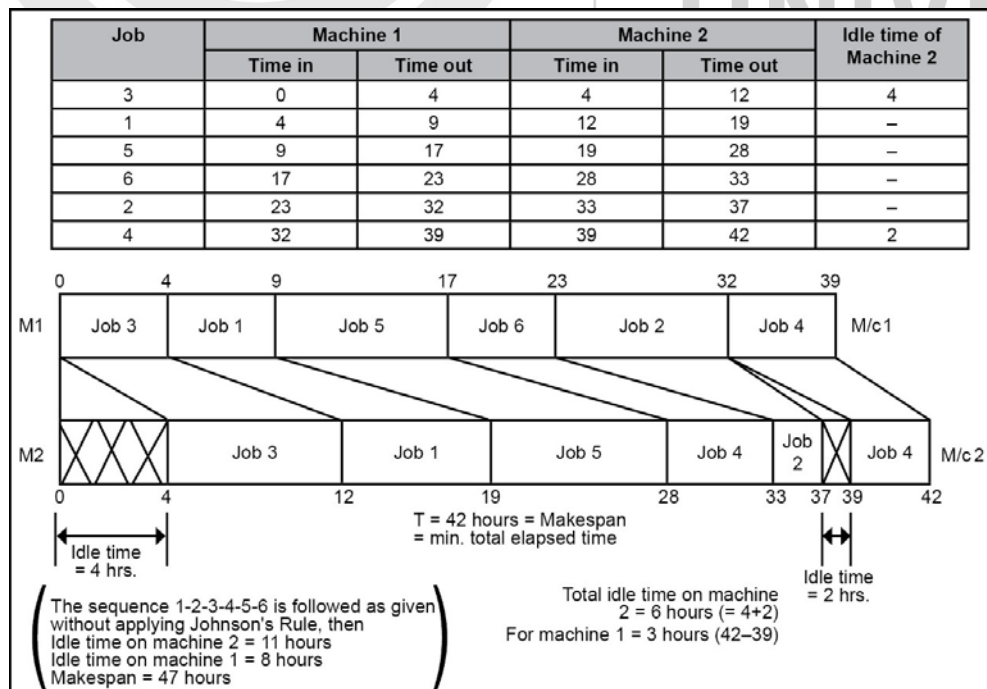


Fig. II GANTT CHART

7.5 TWO JOBS, m MACHINES CASE

When there are two jobs each having its own processing sequence on m machines, the optimal sequence of these jobs on the m machines to minimise the total processing time can be obtained by using a graphical procedure as outlined below:

- 1) Construct a two-dimensional graph where the x axis represents the processing time and sequence of job 1 on the m machines while the y axis represents those of job 2 (Use the same scale for both x and y).
- 2) Shade the areas where a machine would be occupied by the two jobs at the same time.
- 3) The processing of both jobs can be represented by a continuous path which consists of horizontal, vertical, and 45 degree diagonal segments.

The path starts at the lower left corner and stops at the upper right corner, while avoiding the shaded areas in the graph. In other words, the path is not allowed to pass through shaded areas which correspond to operating both jobs concurrently on the same machine. Since a diagonal segment implies that both jobs are being processed on different machines at the same time, a feasible path that maximises diagonal movement will minimise the total processing time. The schedule is determined by trial and error. Usually, only a few lines may be drawn before an optimal path is found.

Example 7.3

Two major parts P_1 and P_2 for a product require processing through six machine centres. The technological sequence of these parts on the six machines and the manufacturing times on each machine are:

P_1	Machine sequence:	C	-A	-E	-F	-D	-B
	Time(hours):	2	3	4	5	6	1
P_2	Machine sequence:	B	-A	-E	-F	-C	-D
	Time(hours):	3	2	5	3	2	3

What would be the optimal scheduling to minimise the total processing time for these two parts?

Solution:

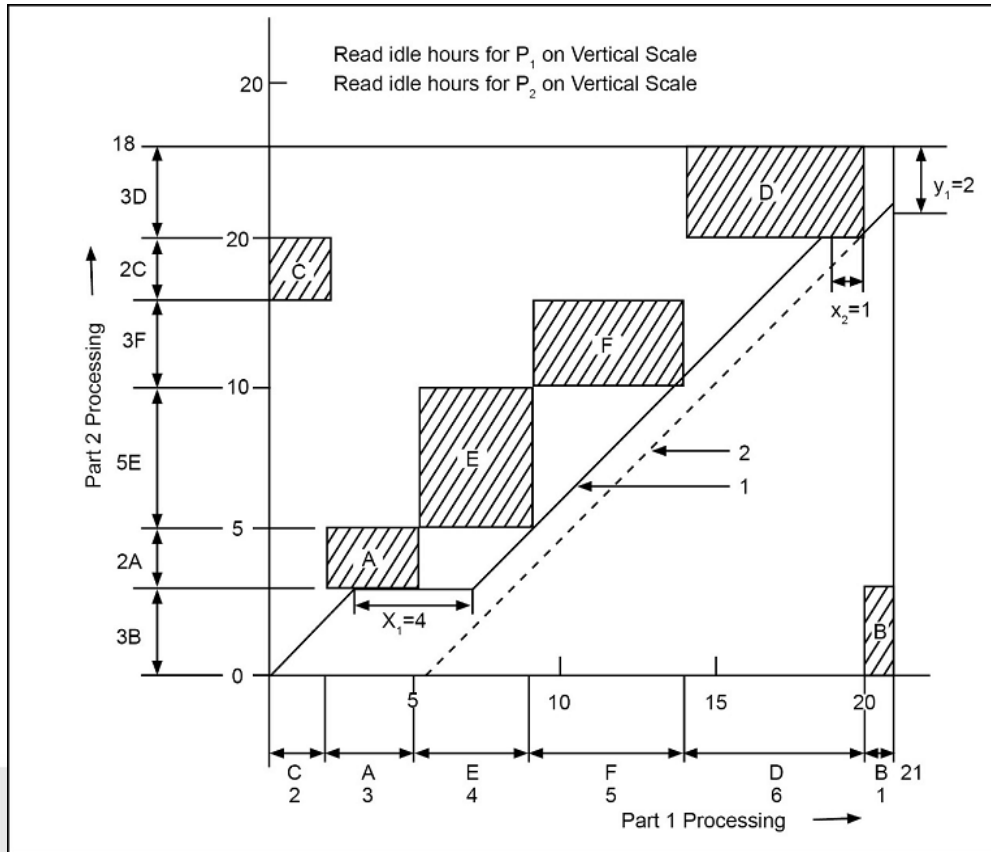
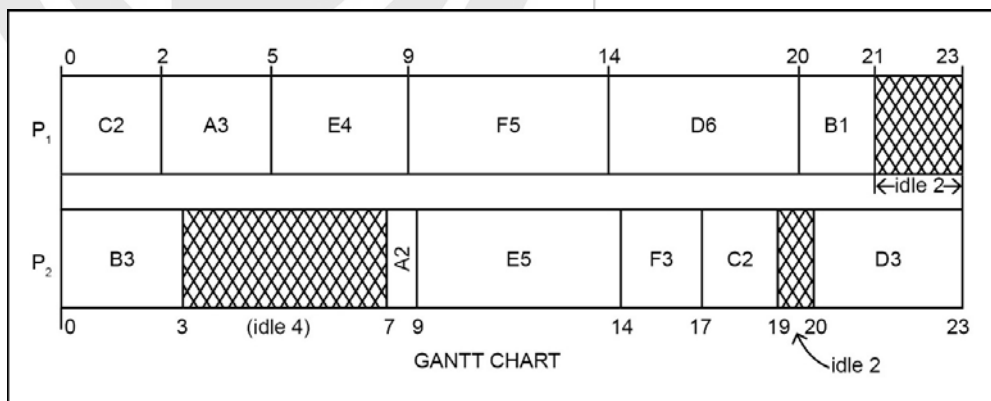


Fig. III: Processing 2 Jobs on 6 Machines

Constructing a two dimensional graph where the horizontal axis represents P_1 and the vertical axis represents P_2 we can shade the areas where both parts use the same machine as shown in Figure III. Lines 1 and 2 maximise the diagonal travel from the bottom left corner to the upper right corner. The total processing time is 23 hours.



7.6 SCHEDULING RULES FOR JOB SHOPS

We have seen that the procedures suggested above apply to very simplified situations involving one or two machines or only two jobs. Moreover, the problem treated was one of a static job or flow shop in which all jobs are available at the beginning of the horizon and the schedule once made is not disturbed till all the jobs are completed.

Unfortunately, even the general static job shop problem of n jobs and m machines ($m > 3$) with the objective of minimising the total completion time does not have a general exact solution procedure. There are some heuristic techniques that may obtain good sequences or even optimal sequences (though it may not be possible to check for optimality). You may, for instance, refer to Campbell, Dudek and Smith and Stinson and Smith for example of such heuristic procedures.

Practical job shops are much more complicated and may have hundreds of machining centres and thousands of jobs. In such cases resort is made to priority dispatching rules for sequencing jobs at each machine centre. These can apply both in a static and dynamic job environment. In the former case priorities of jobs once assigned are not changed whereas in the latter case priorities are updated as jobs enter or leave the machining centre. Some commonly specified priority dispatching rules are:

- | | | |
|-----|---------|---|
| 1) | FCFS: | Select the job on a First Come First Served basis. |
| 2) | SPT: | Select the job with the Shortest Processing Time. |
| 3) | EDD: | Select the job with the Earliest Due Date. |
| 4) | SLACK: | Select the job with the minimum static slack (due date minus time of arrival at machine centre) |
| 5) | RANDOM: | Select the job in random order |
| 6) | LRPT: | Select the job with the Least Remaining Processing Time. |
| 7) | S/OPR: | Select the job with the minimum ratio of job slacktime to the of operations remaining. |
| 8) | LCFS: | Select the job on a Last Come First Served basis. |
| 9) | DS: | Select the job with least Dynamic Slack (time remaining to due date less remaining expected flow time). |
| 10) | DS/ PT: | Select the job with the minimum ratio of Dynamic Slack to Processing Time. |

Based on simulation studies of various job shops, several researchers have come to certain conclusions about the behaviour of these rules. Clearly such behaviour is affected by factors like criteria of performance, level of uncertainty and job arrival pattern.

The SPT rule consistently tends to give the lowest mean flow time even for large shops—a property that has been demonstrated in the simple n job one machine case. However, with the SPT rule the variance of flow times tends to be large. In this, regard other rules such as FCFS perform better. A recent survey of dispatching rules for manufacturing job shop operations has been done by

Blackstone, Phillips and Hogg. The interested reader may refer to this for further details.

7.7 PROBLEMS AND PROSPECTS OF JOB PRODUCTION

Most of the problems in job production arise from the variety of jobs arriving and demanding individual processing sequences on the scarce facilities in the job shop. Owing to these factors the job shop is characterised by the following typical problems:

- complicated and unsystematic material flow patterns
- large in-process inventories
- large waiting times for jobs
- large completion times for jobs
- unpredictable problems owing to the large variety of tasks

We have seen that essentially two kinds of research pertaining to job shop scheduling has been done. In the first case there has been an attempt at developing new procedures for scheduling with a variety of objectives. We have seen some examples of these procedures in Sections 7.3, 7.4 and 7.5. Most of these procedures have been developed for the static job or flow shop. Clearly a lot more could be done in this direction. The major difficulty in large job shops is the combinatorial increase in the number of possible sequences. With better bounds and more efficient computational facilities this problem could be probed further.

The second kind of scheduling research has been to test the efficiency of different priority dispatching rules using simulation. Some of these scheduling rules were described in Section 7.6. The advantage of this approach is that dynamic features can be incorporated and evaluated. There are possibly two extremes for scheduling the new jobs in a dynamic environment: to produce a new schedule each time a new job arrives, or to completely finish the existing schedule before producing a new schedule for the jobs that had arrived in the mean time. Or a solution between the two extremes could be considered. Ignoring computational considerations, one could have an on-line computer system whereby everytime an operation finishes on a machine, this information is fed into the computer. The programme then considers the actual status of the shop at that time and all the relevant data and applies some criterion to select the next operation for that machine. This approach may be computationally very demanding and economically not feasible. Hence less frequent rescheduling

may be done. "What is the right frequency of scheduling with its implications on cost and effectiveness?" This has been an important question for researchers. Some studies in this regard are available in Muhlemann, Lockett and Farm.

7.8 SUMMARY

In this unit we have presented the features of job production which essentially involve the production of a variety of jobs in small production quantities with a limited set of facilities. Each job has its unique processing requirement and thus follows its own path through the shop. The variety of problems that may arise in the job shop have been discussed. Depending on the number of jobs to be scheduled, the number of processing facilities, the type of manufacturing facility (flow shop or job shop), the manner in which jobs arrive at the shop (static or dynamic) and the criterion for evaluating the effectiveness of a schedule, different procedures can be used to determine the optimal sequence. Some procedures for the n job one machine case, n job two machine case and the 2 job m machine case have been discussed with simple illustrative examples.

Some priority dispatching rules used in practical job shops have been presented and comments on simulation studies of job shops have been made. The status of research in job shop scheduling is touched upon and some hints for probable future directions of work are given.

7.9 KEY WORDS

Due Date: The deadline for the completion of a job. There could be some penalty if a job is completed beyond its due date.

Dynamic Arrival Pattern: A situation where jobs arrive intermittently at the shop according to a stochastic process.

Flow Shop: A special type of shop in which jobs proceed sequentially through machines.

Flow Time: The time between the arrival of a job and its completion in the shop. It thus equals processing time plus the time that the task waits before being processed.

Job Shop: A production system consisting of different general purpose facilities used to handle a variety of tasks each with its unique processing requirement.

Lateness: Job completion time minus its due date. A positive lateness indicates that the job is finished after its due date whereas a negative lateness shows that it is completed before its due date (Positive lateness is called tardiness and negative lateness is called earliness).

Makespan: The time to complete all jobs.

Schedule: A time table showing when which job is done.

Sequence: The order in which jobs are done.

Slack: Job's due date minus processing time.

Static Arrival Pattern: A situation where all the jobs to be processed in the shop are available at the beginning of the period, and no new jobs arrive during the processing.

Tardiness: The measure of positive lateness.

7.10 SELF-ASSESSMENT EXERCISES

- 1) What is the distinctive feature of job production as compared to mass and batch production systems?
- 2) Give five examples from your daily life of job production systems.
- 3) For the following data concerning 10 jobs to be processed on one processor determine the minimum mean flow time schedule. What is the minimum mean flow time?

Job i	1	2	3	4	5	6	7	8	9	10
Processing time t_i (hours)	5	6	11	8	12	14	7	10	6	12
Importance weight W_i	3	2	1	3	2	1	3	2	1	1
Due date d_i (hours)	30	30	40	80	100	70	90	80	40	90

(Ans 41.7 hrs) (Follow example 1)

- 4) For the data of problem 3 develop the minimum weighted mean flow time schedule. What is the weighted mean flow time for this schedule?

(Ans 38.62 hrs)

- 5) For the data of problem 3 develop the schedule for minimising maximum lateness? What is the mean flow time for this schedule.

(Ans 45.50 hrs)

- 6) For the data of problem 3 find a schedule that minimises the number of tardy jobs.

(use Hodgson's Algorithm)

- 7) For the data of problem 3 find the schedule which minimises mean tardiness.

(Ans SLACK Rule)

- 8) Eight jobs must be processed through a two machine flow shop. The processing times of each job on both machines are shown below. Determine the schedule to minimise makespan.

Job	1	2	3	4	5	6	7	8
Processing time on M1	10	12	13	7	8	5	4	3
Processing time on M2	4	9	11	8	7	5	10	2

[Ans:- Optimul sequence 7-4-3-2-5-6-1-8 or 7-6-4-3-2-5-1-8, Makespan =65, Idle time for A=3, Idle time for B=9]

- 9) Two jobs are required to go through six machines. The processing times as well as the sequence of each job on the machines are:

Job 1-Sequence	A	-B	-D	-C	-F	-E
Job 1-Times	5	6	4	7	3	4
Job 2-Sequence	B	-A	-D	-C	-E	-F
Job 2-Times	7	5	6	8	2	1

Find the makespan of the optimal sequences.

[Follow Example 3]

7.11 FURTHER READINGS

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UNIT 8 PLANNING AND CONTROL OF PROJECTS

Objectives

After completion of this unit you should be able to:

- describe a project in terms of its activities, represent the inter-relationships among the activities as network and differentiate between CPM and PERT.
- compute activity times, critical paths and slacks, use the above information for the time management of the project and use PERT when activity times are probabilistic.
- specify project cost curve and crashing of the activities for reduction in the time duration of the project and schedule resources.

Structure

- 8.1 Introduction
- 8.2 Projects
- 8.3 Network Representation of Projects
- 8.4 Time Management of the Project
- 8.5 Critical Path Method (CPM)
- 8.6 Programme Evaluation and Review Technique (PERT)
- 8.7 Time Cost Relationship and Project Crashing
- 8.8 Resource Allocation
- 8.9 Project Updating and Monitoring
- 8.10 Summary
- 8.11 Key Words
- 8.12 Self-assessment Exercises
- 8.13 Further Readings

8.1 INTRODUCTION

We are sure that, both in your professional career and in your personal life, you have handled projects. In this unit we will deal with efficient management of projects. We will describe a project as consisting of inter-related activities. Networks will be used as visualisation of these inter-relationships. A successful implementation of the project will involve planning, coordination and control of the activities constituting the project. We will discuss the time-management of project using Critical Path Method and, subsequently, in situations where activity times are probabilistic, Programme Evaluation and Review Technique (PERT). We shall also describe the relationship between cost and time for implementation of the projects. Each project involves consumption

of certain raw materials and use of certain resources. We shall briefly look into the resource allocation problems.

While this unit will outline methods and techniques which are useful in Project Management, a successful implementation of a project will depend on the skill and efficiency of the manager in using these techniques.

8.2 PROJECTS

Before we formally define projects, it will be a good idea if you describe, in your own words, your impression of the word project.

Now consider the following two situations:

- 1) Preparing tea
- 2) Arranging for a tea party

If we look at the above two situations, then arranging for a tea party will require preparing tea as one of the tasks. In fact, arranging for a tea party will require organisation of other tasks, such as issuing invitations, procurement of snacks, procurement of cutlery, table arrangement, serving tea, etc. You will agree that arranging for a tea party is a much more complex task consisting of a large number of simpler tasks or activities such as preparing tea. **We will call arranging for a tea party as a project while we will refer to individual tasks such as preparing tea as activities.** A list of the activities for this project is as follows:

Example 8.1

List of activities for the project **Arranging a tea party**:

- | | | | |
|---|-----------------------------------|---|----------------|
| A | Procure material | B | Prepare snacks |
| C | Arrange for the cutlery | D | Prepare tea |
| E | Set table with snacks and cutlery | F | Serve tea |
| G | Clean cutlery | | |

We shall also make following observations:

- a) Each activity needs physical time for its completion.
- b) Certain activities are inter-related in the sense that tea cannot be actually served until its preparation is completed.
- c) Each activity will require one or more of the resources such as manpower, equipment and raw material, etc.
- d) A project will be completed only if all of its activities are completed.

We will describe formally an **activity** as a physical independent action which requires time for its completion and will consume one or more of the resources,

and a project as a set of inter-related activities that are organised for a common goal or objective

Some of the examples of projects are: erection of a manufacturing plant, preventive maintenance of a chemical plant, launching of a space vehicle and construction of a building, etc. These projects have a very large number of activities and can be successfully completed only if the various activities are properly planned, time schedules are prepared, resources allocated and a proper control is exercised during the implementation. Project management essentially deals with these aspects of the project.

8.3 NETWORK REPRESENTATION OF PROJECTS

First step in the management of the projects is to understand the inter-relationship between the various activities which constitute the project. The activities may be inter-linked with each other in various ways. For example, the activities preparation of tea and preparation of snacks may be inter-linked with each other by the type of resource required (in this case a gas stove). On the other hand, the activity serving tea cannot be started unless and until the activity preparation of tea is completed. Unlike the other example this dependence cannot be freed by providing additional resources.

Thus in any feasible time-schedule, activity serving tea has to be scheduled only after the completion of the activity preparation of tea. This kind of interdependence will be referred to as precedence requirement. An activity B is said to succeed activity A if, in any feasible time-schedule, B has to be scheduled only after completion of A. Then, A is said to be the predecessor of B.

Project Networks are used to visually depict through arrow diagrams these precedence requirements.

Drawing Project Network

The input required to draw project network is the list of the activities and their precedence requirements. When considering the precedence requirements, only immediately preceding activities will be listed. These are also called immediate predecessors. Consider the precedence requirements of the Example 1.

To start the activity prepare snacks, material has to be procured and hence A will precede B. Similarly A will also precede C. Activity E can start only when A, B, D are completed. However, as A precedes B, it is not necessary to list A as the preceding activity to E. Thus, B, D as a set of preceding activities to E, is sufficient to enforce all the precedence requirements. For the above example, you may check that the list of precedence requirements is as follows.

From the list of precedence activities, project network is drawn using arrows. Each activity is represented as an arrow, which is a line with a small circle at each end called node. Figure 1 represents one such activity.

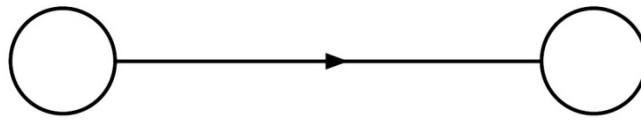


Fig I: Activity in a Network

If an activity A precedes another activity B then the end node (circle) of activity A is merged with the start node (circle) of activity B. Thus the following diagram, will represent the precedence requirement A precedes B.

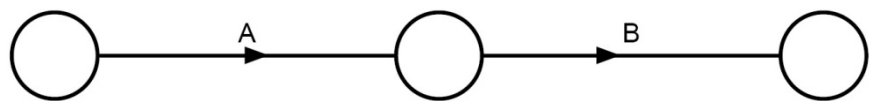


Fig II: Precedence Representation

If an activity such as activity E in the project arranging a tea party has more than one predecessor (B, D in this case) the end points of all the predecessors are merged with the start node of this activity. Thus Figure III represents B and D precede E.

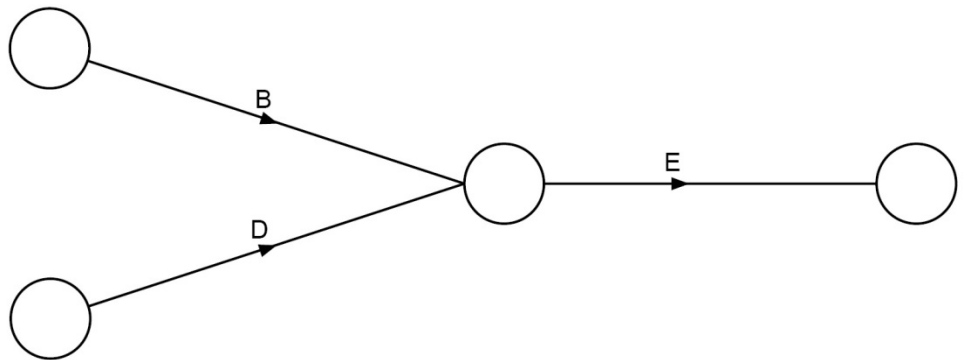


Fig III Two Activities Preceding One Activity

Using the above method the project network for the project arranging a tea party is as in Figure IV.

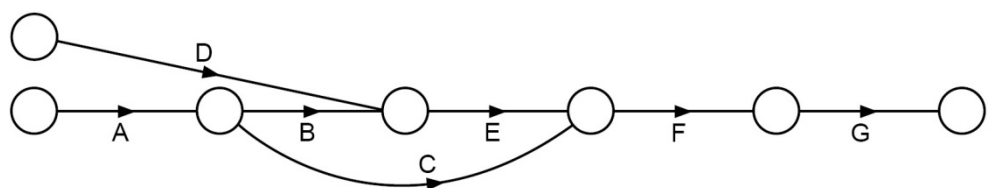


Fig IV Network for Preparing Tea

For further convenience, the starting node of all the activities with no predecessors are joined together, as they can be started at the same time. With this modification the network will look like as follows:

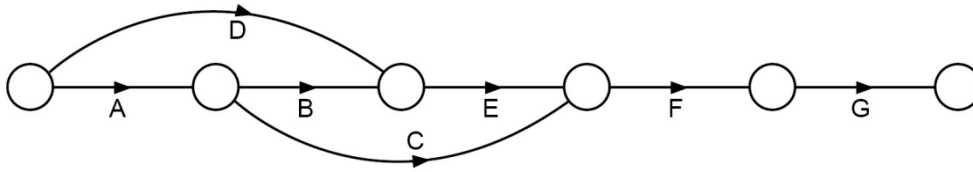


Fig V: Correct Network For Preparing Tea

The node (or circles) in the arrow diagram are referred to as event. Events are well defined points in time, at which an activity can be started.

As another example 8.2, consider a project with following precedence requirement:

Activity/week

A 3
B 5
C 7
D 3
E 7
F 3
G 2
H 2

Immediate predecessors

C
A,B
E,D
D
F,G

Now Try to draw a network for the example 8.2.

-While you will be able to draw the diagram upto the activity F without any problem (Figure VI), you will find difficulty in correctly showing G, which has only D as its predecessor. Representation in Figure VII is not correct, as in it both D and E are required to precede G -while it can start as soon as D is completed.

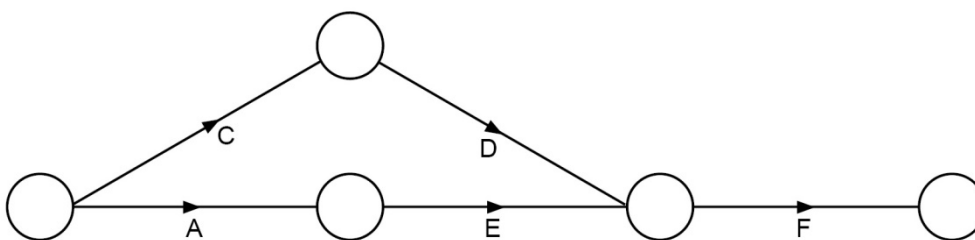


Fig VI: Partial network for Example 8.2

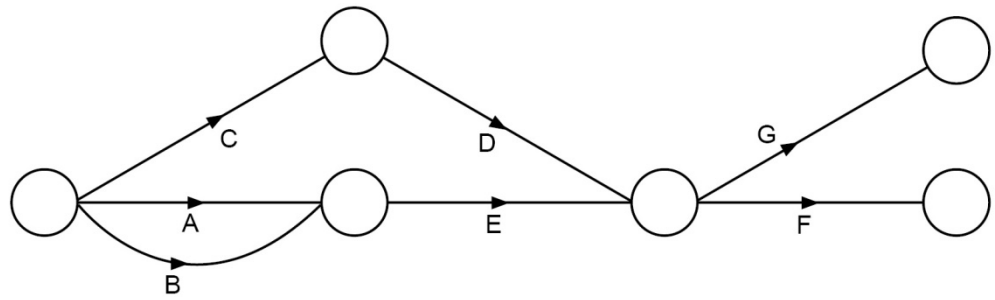


Fig VII: Incorrect precedence Representation for Example 8.2

The Correct representation is shown in fig. VIII

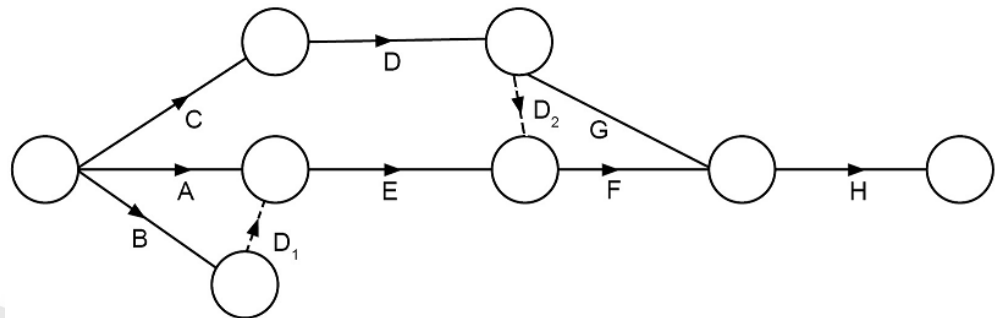


Fig VIII: Correct Network for Example 8.2

The dotted arrows are called dummy activities and are activities which take zero time. Thus the activity F can be started only when both D and F. are completed but G can be started as soon as D is completed. In addition another dummy is added after activity B. The purpose here is to make sure that one pair of events connects only one activity.

Thus in project network dummy activities are. added to:

- 1) Ensure correct precedence relationship.
- 2) Make sure that two events are joined at most by one arrow.

Node Labelling

Once the network is drawn, it is a good practice to label the events systematically. A standard procedure is as follows:

- 1) A start event is the one which has arrows emerging from it but none entering into it. Find the start event and number it 1.
- 2) Delete all the arrows emerging from all numbered events. This will create at least one new start event out of the remaining events.
- 3) Number the new start events as 2, 3 and so on.
- 4) Repeat steps 2 and 3 until end event is reached. Consider the diagram in Figure VIII. The above procedure will lead to the following node numbering.

Consider the network shown in Figure X. Try to number the node as per procedure for the following activities listed below.

The diagram shows a directed graph with five nodes (circles) and five edges (arrows). The edges are labeled A, B, C, D, and E. The graph structure is as follows:

- Node 1 (leftmost) has an outgoing edge labeled A to Node 2.
- Node 2 has an outgoing edge labeled B to Node 3 and an outgoing edge labeled C to Node 4.
- Node 3 has an outgoing edge labeled E to Node 5 (rightmost) and an incoming edge labeled D from Node 4.
- Node 4 (bottom) has an incoming edge labeled C from Node 2 and an outgoing edge labeled D to Node 3.

```
graph LR; N1(( )) -- A --> N2(( )); N2 -- B --> N3(( )); N2 -- C --> N4(( )); N4 -- D --> N3; N3 -- E --> N5(( ))
```

8.4 TIME MANAGEMENT OF THE PROJECT

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- 1) Projects in which activity times can be estimated with sufficient certainty, for example-building a house, or erecting a plant.
- 2) Project in which there is high degree of uncertainty about the activity times. For example-launching a space vehicle, developing a new product, etc.

Time Management of the project is the first case that is usually done by using Critical Path Method (CPM) and in the second case using Programme Evaluation and Review Techniques (PERT).

As an exercise let us consider a simple activity like preparing tea. Estimate activity time for this activity; clearly write down the method which you have used for arriving at this estimate.

Repeat this for the following activities:

- a) Changing punctured wheel of a scooter.
- b) Getting a cheque encashed from the Bank.
- c) Travelling from your home to office.
- d) Preparing a report for your boss.
- e) Travelling from your home to a new place (which you have not visited before)

It is an exercise to you to summarise various methods which can be used to arrive at the activity times.

8.5 CRITICAL PATH METHOD (CPM)

In this method it is assumed that activity durations are deterministic or are known with certainty. The method will compute the earliest possible start time and latest possible start time for each activity. In addition it will identify the critical activities. These activities are critical in the sense that if completion of any of these activities is delayed even by a short period of time, the whole project will be delayed. For other activities, slacks (floats) will be computed which will give some idea of the relative importance of these activities in terms of their time-management. To illustrate the computations at various times we will discuss the example 8.2 whose network representation with node number is shown in Figure XI.

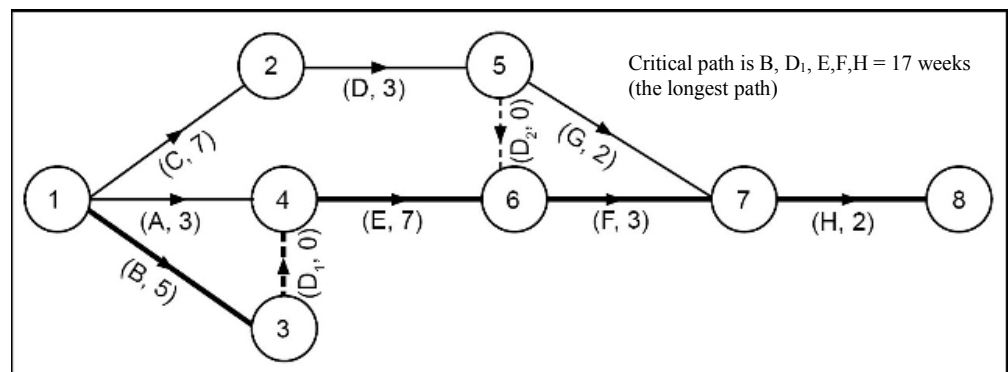


Figure XI: Network with activity times for Example 8.2

Let the activity times of activities A, B, C, D, E, F, G, H be 3, 5, 7, 3, 7, 3, 2, 2 weeks respectively.

Figure XI shows the project network with activity times. In this Figure (C,7) on the arrow 1,2. indicates the activity name C and its duration as 7 weeks.

Computations of Early Start and Early Finish Times for the Activities

Once the network is developed and the activity times are compiled we wish to compute the earliest time by which an activity can be started. For any activity (j) we shall refer this time as ES(j). Let the activity time for the activity j be denoted by T (j). In example 8.2 activity A, B, C can begin at time zero. Hence we can assign ES (A)=0, ES(B)=0, ES(C)=0. You may note that all the three activities can start at the same time. Earliest time by which an activity (j) can be completed will be denoted by Earliest Finish Time EF(j). As the activity time for activity (j) is 't(j) then its Earliest Finish Time'EF(j) is,

Thus

$$\begin{array}{rclcl} \text{EF (j)} & = & \text{ES(j)} & + & \text{T(j)} \\ \text{EF (A)} & = & 0 & + & 3 = 3 \\ \text{EF (B)} & = & 0 & + & 5 = 5 \\ \text{EF (C)} & = & 0 & + & 7 = 7 \end{array}$$

Activity D can be started only when activity C is finished, while activity E can be started only if both the activities A and D₁ are finished. We can compute the times associated with these activities as follows:

$$\text{ES (D)} = \text{EF (C)} = 7, \text{EF (D)} = \text{ES (D)} + \text{T(D)} = 7 + 3 = 10$$

$$\text{ES (D}_1\text{)} = \text{EF (B)} = 5, \text{EF (D}_1\text{)} = \text{ES (D}_1\text{)} + \text{T(D}_1\text{)} = 5 + 0 = 5$$

$$\text{ES(E)} = \text{maximum (EF(A), EF(D}_1\text{))} = \text{maximum (3, 5)} = 5$$

$$\text{ES (E)} = \text{ES(E)} + \text{T(E)} = 5 + 7 = 12$$

Similarly

$$\text{ES(G)} = \text{EF(D)} = 10, \text{EF (G)} = 10 + 2 = 12$$

$$\text{ES (D}_2\text{)} = \text{EF (D)} = 10, \text{EF(D}_2\text{)} = 10 + 0 = 10$$

$$\text{ES (F)} = \text{max (EF (D}_2\text{), EF (E))} = \text{max (10, 12)} = 12 \text{ and } \text{EF (F)} = 12 + 3 = 15$$

$$\text{ES (H)} = \text{max (EF(G), EF(F))} = \text{max (12, 15)} = 15, \text{EF (H)} = 15 + 2 = 17$$

$$\text{ES(H)} = \text{max (EF(G), EF(F))} = \text{max (12, 15)} = 15, \text{EF (H)} = 15 + 2 = 17$$

Thus the activity H will be completed on the 17th week and hence the project can be completed by the 17th week from its start.

You may note that while all the activities together require 32 weeks but they can be completed in 17 weeks as some of them can be completed simultaneously.

However, as the precedence relationship require certain activities to run sequentially, the project cannot be completed before 17th week.

We can summarise the rules for computations of Early Start Time and Early Finish Time as follows:

- a) All the activities which do not have any preceding activity can be started at time zero.
- b) Earliest Start Time for an activity can be computed only if the Earliest Finish Times (and hence Earliest Start Times) for all its preceding activities are computed.
- c) Earliest Start Time for an activity (j) is the earliest time by which all its preceding activities are completed,

$$\begin{aligned} \text{ES (j)} &= \text{largest finish time among all its preceding activities} \\ &= \text{maximum } \{ \text{EF (i)} \} \text{ over all preceding activities i} \end{aligned}$$

Critical Path

A path in a network is a sequence of activities which have to be completed sequentially due to precedence requirements. Thus C, D, G, H is a path and so are (A, E, F, H), (B, D₁, E, F, H), (C, D, D₂, F, H). Time duration of the path is the sum of the activity times of the activities forming the path. The path or paths with the largest time duration in the network is (are) called critical path(s). All the activities on the critical path(s) are called critical activities. The earliest time by which a project can be completed is the time duration of the critical path(s). If an activity on the critical path is delayed the whole project will get delayed. Thus for timely completion of the project it is essential that all critical activities be started at the earliest start time and be completed in the planned duration.

A method of computing critical path(s) can be to enumerate all the paths in a network and to compute the time duration of each of these paths and then to select the path(s) with largest time duration. However, in a large network such enumeration will take large amounts of computation time even on very fast computers. Another mechanism will be to identify those activities which are critical. This can be done by finding the Latest Start Time for each activity. This is the time by which if the activity is started, the project will be completed in time. For critical activities Latest Start Time and Earliest Start Time will be identical.

$$\text{Path C,D,G,H} = 7+3+2+2 = 14, \text{ A,E,F,H} = 3+7+3+2 = 15$$

$$\text{B,D}_1, \text{ E,F,H} = 5+0+7+3+2 = 17, \text{ C,D,D}_2, \text{ F,H} = 7+3+0+3+2=15$$

B, D₁, E, F, H = 17 weeks (longest) is the critical path and is shown in heavy lines.

Computations of Latest Start Time and Latest Finish Time of Activities

Latest Start Time of an activity j, LS(j) is the time by which, if it is started the project will get completed in time. Any delay beyond this time in the starting of the activity or in its execution will delay the completion of the project. In our

example, if the project has to be completed by 17th week, the activity H has to be finished by 17th week. Hence if the latest finish time of the activity H, $LF(H)$, is 17 weeks,

$$LF(H) = 17$$

and $LS(H) = 17 - T(H) = 17 - 2 = 15$

It may be noted that for activity H:

$$ES(H) = LS(H) = 15$$

However, activity G can be completed by 15th week, without delaying the project as in that case H can still be started on the 15th week and completed by 17th week.

Hence, $LF(G) = LS(H) = 15$, $LS(G) = 15 - 2 = 13$

While for the activity G $ES(G)$ is 10, $LS(G)$ is 13 weeks. Thus it is possible to delay the start of G upto 13th week without delaying the project completion. Similarly,

$$LF(F) = 15, LS(F) = 15 - 3 = 12, LF(D_2) = LS(F) = 12$$

$$LS(D_2) = 12 - 0 = 12$$

$$LF(E) = LS(F) = 12, LS(E) = 12 - 7 = 5$$

However, latest point in time by which the activity D should be completed is the point in time such that both D_2 , (hence F) and G can be started by their Latest Start Time.

$$\text{Thus } LF(D) = \text{minimum } \{LS(D_2), LS(G)\} = \{13, 12\} = 12.$$

$$LS(D) = 12 - 3 = 9$$

If D is not completed by 12th week, F has to be started later than its Latest Start Time resulting in the project delay.

Similarly,

$$LF(C) = LS(D) = 9, LS(C) = 9 - 7 = 2$$

$$LF(A) = LS(E) = 5, LS(A) = 5 - 3 = 2$$

$$LF(D_1) = LS(E) = 5, LS(D_1) = 5 - 0 = 5$$

The table gives the ES, LS, EF, LF for all the activities. In the fifth column, the difference between LS and ES is listed as slack.

Table 2: Computations of Activity Times

Activity	Activity Duration	ES	EF	LS	LF	Slack
A	3	0	3	2	5	2
B	5	0	5	0	5	0
C	7	0	7	2	9	2
D	3	7	10	9	12	2
E	7	5	12	5	12	0
F	3	12	15	12	15	0
G	2	10	12	13	15	3
H	2	15	17	15	17	0
D ₁	0	5.	5.	5	5	0
D ₂	0	10	10	12	12	2

The activities B,E,F,H are critical and will form the critical path. We can summarise the procedure for the computation of latest start and latest finish time for the activities as follows:

- All the activities without any successor are required to be completed by the time project is completed and hence for all these activities

$$LF(j) = \text{Project completion time}$$

$$LS(j) = LF(j) - T(j)$$

- The latest an activity can be completed without delaying the project is the time such that all its succeeding activities can be started latest by their latest start time $LF(j) = \text{maximum } \{LS(i)\}$ overall successor i

$$\text{and } LS(j) = LF(j) - T(j)$$

- Latest Start Time for an activity can be computed only if the Latest Start Times of all its successor have been computed.

In all we have observed that all activities, for which Early Start Time and Latest Start Time are same or which have zero slack, are critical activities and the path(s) formed by these activities will be the critical path(s). All other paths are known as non-critical paths.

Slack (Float) (Slack is used for events and float for activities)

In the computation of the activity times, we observed that slack or total float in an activity is the difference between its Latest Start Time and its Earliest Start Time. It signifies the delay which is permitted in the completion time of that activity without affecting the project completion. The delay can be either due to delay in completion of its preceding activities or in the execution of this activity itself. You may note that while both the activities C and D have slack of 2 days each, both of them cannot be delayed simultaneously. If C is completed 1 week late i.e. on 8th week then slack available on D will be only one week. **In some cases it may be useful to compute free slack (float) which is the slack**

available in an activity such that early start of the successors are not affected. In other words, free slack is the delay which, if occurs, will not effect the early start of the successors. By this definition, the free slacks for the various activities for the example 8.2 are as follows:

$$\text{Free slack (C)} = \text{ES(D)} - \text{EF(C)} = 7 - 7 = 0$$

$$\text{Free slack (D)} = \begin{bmatrix} \text{ES(D}_2) - \text{EF(D)} \\ \text{ES(G)} - \text{EF(D)} \end{bmatrix} = \begin{bmatrix} 10 - 10 \\ 10 - 10 \end{bmatrix} = 0$$

$$\text{Free slack (G)} = \text{ES(H)} - \text{EF(G)} = 15 - 12 = 3$$

$$\text{Free slack (A)} = \text{ES(E)} - \text{EF(A)} = 5 - 3 = 2$$

On other activities free slack will be zero. Why ?

The total slack and free slack can be effectively used for better management of projects. For example, if there is a resource constraint then it will be better to allocate resources first to activities with zero or small slacks.

8.6 PROGRAMME EVALUATION AND REVIEW TECHNIQUE (PERT)

Critical Path Method (CPM) is an effective tool for project planning and control when activity times are known with certainty. However, in certain projects like Research and Development projects, it seems unrealistic to assume that we can know with certainty the time durations in which the activities can be completed. In such cases PERT can be used.

Time Estimates in PERT

In PERT for each activity, three time estimates are made. These estimates are:

- Most Likely Time (TM): The time which is taken most frequently by the activity.
- Optimistic Time (TO): The time by which activity can be completed, if everything went well.
- Pessimistic Time (TP): The time by which the activity will get completed even under adverse conditions.

From the above time estimates expected time of the activity (j), TEO), is computed using following relationship:

$$\text{TE(j)} = \frac{\text{TO(j)} + 4\text{TM(j)} + \text{TP(j)}}{6}$$

The expected time for an activity represents the average time it would take if the activity is performed over and over again. It is different from most likely time. The above relationship is based on the fact that the probability distribution

function of the activity time can be approximated by a **Beta distribution** which is of the shape shown in Figure XII

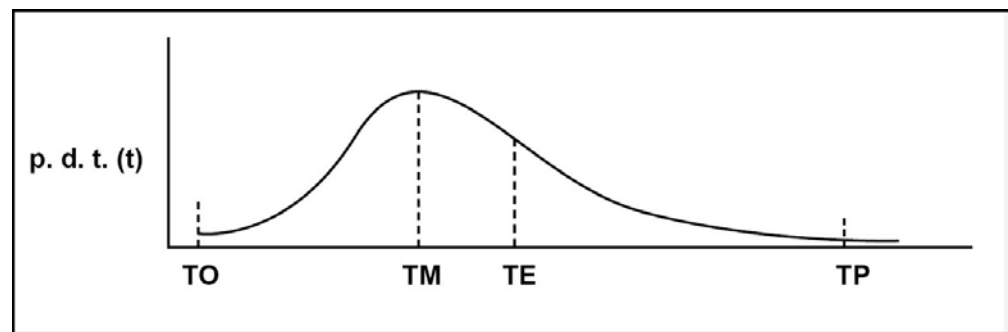


Fig. XII: Beta Distribution

Further, consider two distributions, with the following activity times,

	Activity A	Activity B
TO	3	2
TM	5	4
TP	7	12

Both the activities have same expected time of 5 weeks but there is a higher degree of uncertainty associated with Activity B. This variability can be measured by computing the standard deviation of the activity, $SD(i)$, as

$$SD(i) = \frac{TP(i) - TO(i)}{6}, \text{ thus, } SD(A) = \frac{7-3}{6} = 4/6$$

$$SD(B) = \frac{12-2}{6} = 10/6$$

Variance is defined as the square of the standard deviation and hence

$$V(i) = [SD(i)]^2 = \left[\frac{TP(i) - TO(i)}{6} \right]^2$$

For the example 8.2 the three time estimates, expected time and the variance of the activities are given in the Table 3

Table 3
Estimates of the Activity Times

Activity	TO	TM	TP	TE	SD	V
A	1	2	9	3	4/3	16/9
*B	2	4	12	5	5/3	25/9 *
C	4	6	14	7	5/3	25/9
D	1	3	5	3	2/3	4/9
*E	1	8	9	7	4/3	16/9 *
*F	2	3	4	3	1/3	1/9 *
G	1	2	3	2	1/3	1/9
*H	1	2	3	2	1/3	1/9 *

*Activities on the critical path.

Time of the Project Completion

Unlike CPM, in the case when there is uncertainty in activity times, it is not possible to compute the time of completion of the project with certainty. Instead, we shall estimate the expected time and variance of the project completion time. The expected project completion time $E(T)$, can be computed as the length of critical path in the CPM, when activity times are replaced by the expected times (TE) of the activities. As in the case of example 8.2, TE are same as the activity time in Figure XII, the expected time of the completion of the project is 17 weeks. Further a crude estimate of the variance of the completion time can be obtained by adding the variances of the activities on the critical path.

Thus V (completion time) = Sum of variances of the activities on the critical path

$$= V(B) + V(E) + V(F) + V(H)$$

$$= \frac{25}{9} + \frac{16}{9} + \frac{1}{9} + \frac{1}{9} = \frac{43}{9} = 4.77$$

$$SD \text{ (Completion time)} = \sqrt{V} = \sqrt{4.77} = 2.18 \text{ (SD = Standard Deviation)}$$

Probability estimates of the completion time of the project can be made using the fact that the project completion time has normal probability distribution with mean as expected completion time and Variance as variance of the Critical-Path.

Further analysis of the network can be done using Simulation from which an estimate of the probability that an activity will become critical can be obtained. This is called critical index of the activity.

8.7 TIME COST RELATIONSHIP AND PROJECT CRASHING

In addition to time-management, cost plays an important role in any project. The project costs can be classified in two groups: direct activity costs and indirect project costs. Direct activity costs are those components of the cost which can be directly linked with the activity. Thus direct labour, material consumed, rental charges for the equipment etc. will form part of these costs. Usually, the activity durations can be reduced by increasing the direct activity cost. For example, by asking the labour to work with over-time or with efficiency bonus for faster work etc.

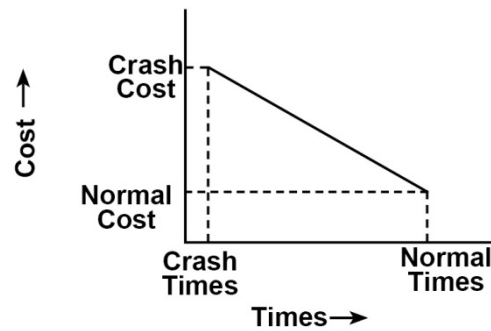


Fig. XIII Time Cost Relationship for an Activity

Crash time is the minimum possible time in which the activity can be completed and the cost associated with this time is the crash cost. Normal cost is the cost incurred when activity is completed in its normal time (or the time used as activity time in the critical path computations).

On the other hand, **indirect costs** are the overheads associated with the entire project including loss of revenue/benefits due to late completion of the project. This cost will decrease directly with the decrease in the project completion time. **An optimal project completion time will be the time for which sum of these two costs is minimum.** To obtain the optimal time, we have to compute direct activities cost when project duration is reduced by one unit time each time. This is called project crashing. We shall explain the project crashing by the following simple example.

Example 8.3

Let the information regarding project be summarised in Table 4.

Table 4: Data for Example 3

Activity	Preceding activities	Normal time (week)	Crash time (week)	Normal Cost (Rs.)	Crash Cost Rs.
A	-	5	4	600	800
B	-	3	1	400	600
C	-	8	5	900	1200
D	A	4	2	600	1200
E	B	4	3	500	700

Given Indirect Project Cost = Rs. 450/Week

We shall assume that cost of crashing an activity by 1 week

$$= \frac{\text{Crash Cost} - \text{Normal Cost}}{\text{Normal time} - \text{Crash time}}$$

$$\text{Cost of reducing by 1 week} - A = \frac{800 - 600}{5 - 4} = 200$$

Similarly for B = 100/week, C = 100/week, D = 300/week, E = 200/week

The project network is shown in Figure XIV(a).

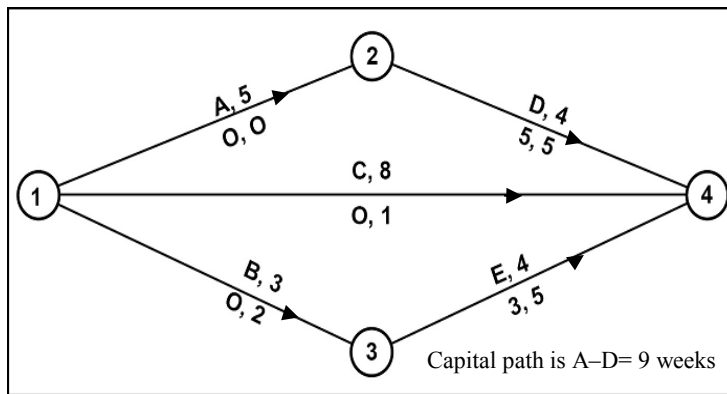


Fig. xiv(a)

Solution

In Figure xiv(a), E,4/3,5 denote Activity E, $T(E) = 4$ and

$ES(E) = 3$, $LS(E) = 5$. For this example project completion time T is 9 weeks and the direct activity cost is Rs. 3000 = (600+400+900+600+500). Project Crashing is shown by steps.

Step 1

If the project completion time is to be reduced by 1 week, it can be done only by reducing the activity duration of one of the activities on the critical path. If there are more than one critical parts then at least one activity on each path has to be crashed. You may note that reducing activity time of any activity other than critical activities will not reduce the length of critical path and hence the project duration cannot be reduced. In our example critical path consists of activities A and D. If the duration of either A or D is reduced by 1 week the length of this path will be reduced to 8 weeks and hence project duration will be reduced to 8 weeks. The cost of reducing the activity A by 1 week is Rs. 200 and of D Rs. 300 and hence it will be beneficial to crash activity A by 1 week. So for $T=8$, direct activity cost is Rs. 3200 = (3000+200). Further the new project network is shown in Figure XV(b).

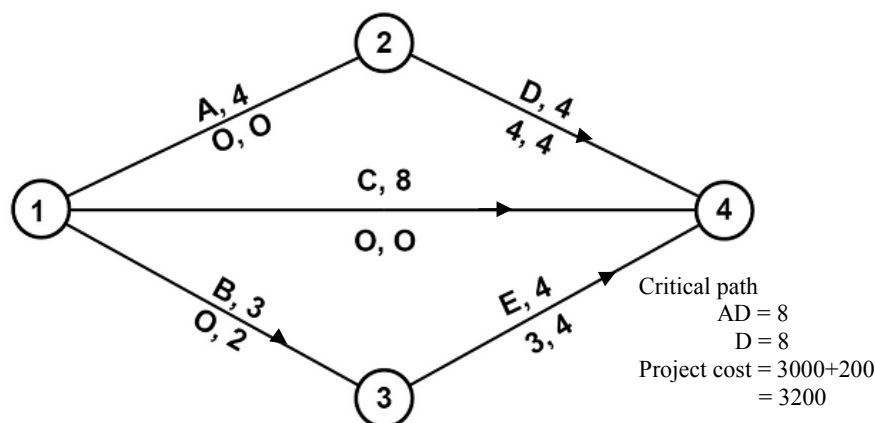


Fig. xiv(b)

Next Crash C and D 1 w each

↓ ↓
100/w 300/w

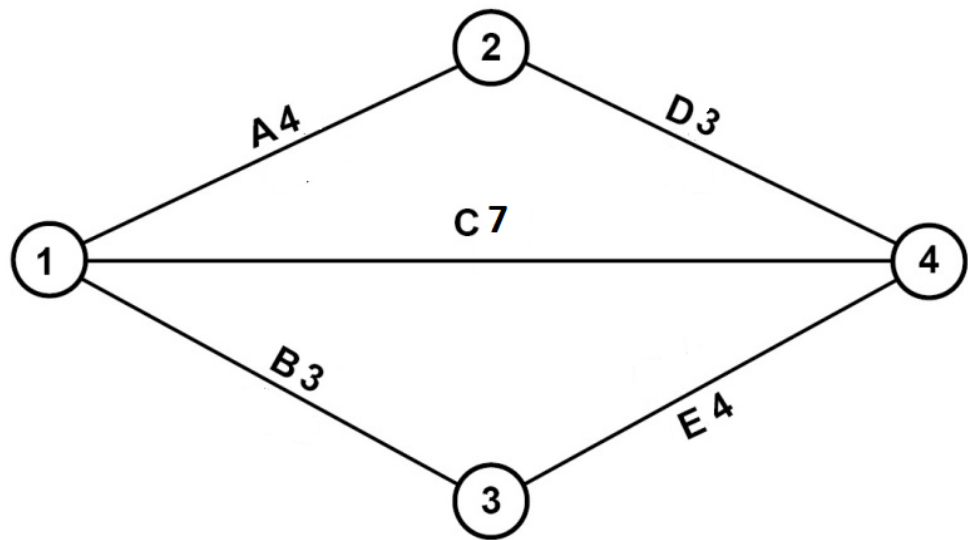


Fig. (c)

Fig. (c) Critical path A-D = 7

$$C = 7$$

$$B-E = 7$$

$$\begin{aligned} \text{Project Cost} &= 3200 + 100 + 300 \\ &= 3600 \end{aligned}$$

Next Crash D, C, B each by 1w

$$\begin{array}{ccc} \swarrow & \downarrow & \searrow \\ 300/w & 100/w & 100/w \end{array}$$

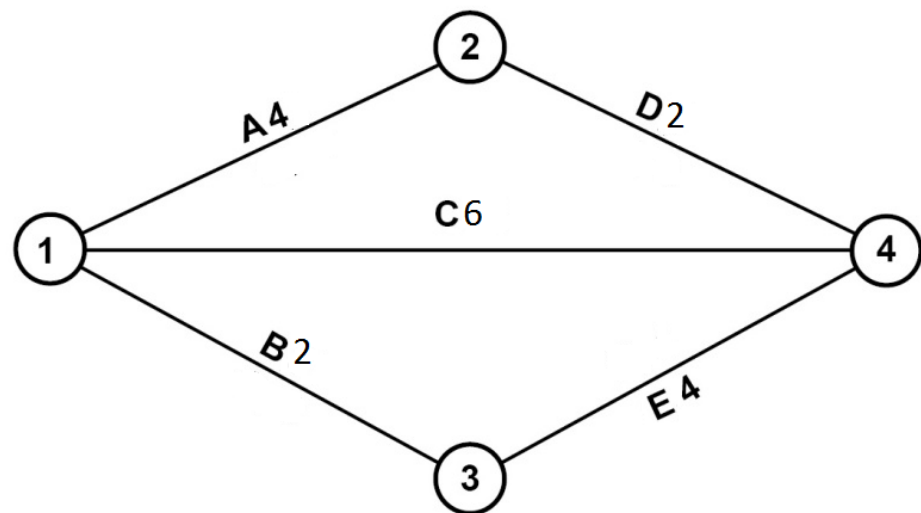


Fig. (d)

Fig. (d) Critical path A-D = 6

$$C = 6$$

$$B-E = 6$$

$$\begin{aligned} \text{Project Cost} &= 3600 + (300 + 100 + 100) \\ &= 4100 \end{aligned}$$

Further Crashing NOT possible

Step 2

Both the paths A-D, and C are critical in this network. To reduce the project duration further, at least one activity on each of the critical paths has to be reduced. It implies that activity A or activity D has to be crashed.

However, it is not possible to crash activity A as already it has been done to its crash time and no further reduction is possible. Hence, we can reduce the project duration by 1 week by crashing C and D, which will cost Rs. 400 (=100+300). (see Fig c). We can repeat crashing process for further reduction in the project duration.

Step 3

Identify all the critical paths. Select one activity on each critical path (same activity can be on more than one critical paths) such that the total cost of crashing all these activities by one unit time is minimum among all such combinations of the activities. Further the activities selected should be such that their current activity time is higher than the crash time, i.e. no time reduction in activity duration can take place beyond its crash time. If there is at least one critical path, on which none of the activities can be crashed, then no further reduction in the project completion time can take place. In that case stop to take any further action.

Reduce the activity time for the activities selected for crashing by unit time period and recompute the Early Start Time, Late Start Time and critical paths for the network. Crash D (300/w), C (100/w) and B(100/w) by 1 week each. See fig (d). Now A-D = 6, C=6, B-E=6, Project cost = 3600 + (300 + 100 + 100) = 4100. Further crashing NOT possible.

The whole sequence of crashing is shown through figures XV(a) to XV(d).

Using the above method the computation for the example 8.3 are as follows:

Table 5: Project Crashing

Current Project Completion time	Critical Path(s)	Activities which can be crashed	Cost of crashing	Activities selected	Cost	Total Cost	Time
9	A – D	A,D	200, 300	A	200	3200	8
8	A – D	D	300	D	300		
	C	C	100	C	100		
7	A – D	D	300	D	300	4100	6
	C	C	100	C	100		
	B – E	B,E	100, 200	B	100		
6	A – D	-	-	-	-		
	C	C	100	-	Cannot be crashed		
	B – E	B, E	100, 200	-	-		

The direct project cost curve is given in Figure xv. The indirect project costs are Rs. 450 per week, then the optimal project duration will be 7 weeks (Total cost = 6750. Least Cost).

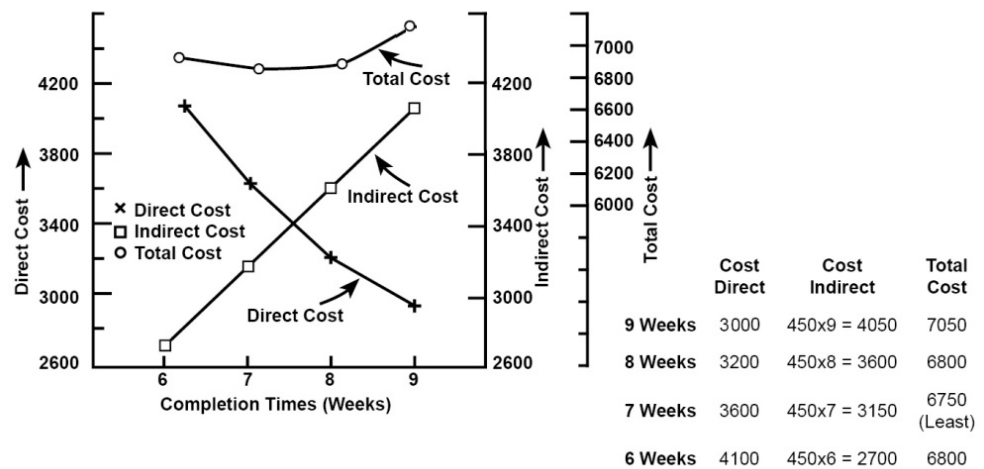


Fig. xv. Project Time-Cost Relationship

8.8 RESOURCE ALLOCATION

The analysis up to this point has been based on the assumption that if its predecessors were completed, an activity could begin. Underlying this assumption is the fact that sufficient resources will be available to start activities simultaneously. However, in actual practice some of the resources may be available in limited quantities.

Examples of such resources are expensive equipment, skilled manpower and finances etc. For example, let each of the activities A, B, C, D, E in the example 8.3 require 2 carpenters and let there be only 4 carpenters available. It is obvious that activities A, B, C cannot be started at 0 time period as, they will require 6 carpenters. In fact, only 2 of these activities can be selected. Third activity can be started only when one of these two will get completed. Depending on which two activities are selected, project completion time will change. An efficient manager will like to apportion resources in such a way that increase in project duration is as low as possible. Many heuristic methods (simple rules) have been developed for such resource allocation problems. While such method cannot guarantee that the solution obtained is best possible, they usually provide good solutions. A simple heuristic rule will be as follows:

- Step 1:** Allocate resources serially in time. That is, start on the first time period and schedule all activities possible with the resources available, then do the same for the second time period and so on.
- Step 2:** When several activities compete for the same resources, give preference to the activities with the least slack. Recompute the slacks in all the activities.

Step3: Reschedule non-critical activities, if possible, to free resources for scheduling critical or non-slack activities.

The computation for Example 8.3 are shown in Table 6. This project will get completed in 12 weeks instead of 9 weeks as scheduled earlier.

Table 6: Resource Allocation

Week	Activities which can be scheduled	Activity time slack		Carpenter needed	Carpenters allocated	
0	A	5	0	2	2	
	C	8	1	2	2	
	B	3	2	2	—	
1	A	4	0	2	2	
	C	7	1	2	2	
	B	3	1	2	—	
2	A	3	0	2	2	(Reschedule)
	C	6	1	2	—	
	B	3	0	2	2	
3	A	2	0	2	2	T = 10 (reschedule)
	C	6	0	2	—	
	B	2	0	2	2	
4	A	1	1	2	2	
	B	6	0	2	2	
	C	1	1	2	—	
5	D	4	1	2	—	
	C	5	0	2	2	
	B	1	0	2	2	
6	D	4	0	2	2	
	C	4	0	2	2	
	E	4	0	2	—	
7	D	3	1	2	2	T = 11 (reschedule)
	C	3	1	2	—	
	E	4	0	2	2	
8	D	2	1	2	—	(reschedule)
	C	3	0	2	2	
	E	3	0	2	2	
9	D	2	0	2	2	(Reschedule)
	C	2	0	2	2	
	E	2	0	2	—	
10	D	1	1	2	2	(Reschedule) T = 12
	C	1	1	2	—	
	E	2	0	2	2	
11	C	1	0	2	2	
	E	1	0	2	2	

8.9 PROJECT UPDATING AND MONITORING

For effective use of the above techniques it is essential that project progress should be continuously monitored. As and when there is a change in time schedule of any activity, the project network should be updated and new time schedule finalised.

Now a days with most of the computers, well written CPM/PERT packages including project crashing and resource allocation are available. These packages will provide all the necessary information needed for efficient project management.

8.10 SUMMARY

Projects are non-repetitive large tasks. A systematic way of describing a project is through identification of activities and their inter-relationships. These inter-relationships can be visualised using arrow diagrams or networks. Project management deals with time-scheduling and resource allocation for these activities. If the activity times are deterministic then Critical Path Method can be used as a systematic method to compute early start and late start times of activities and to, identify critical activities. The slacks associated with each activity can be used for better control of the project. When activity times are probabilistic, PERT is an effective tool. In this method three time estimates are made for each activity and these are used to compute expected project completion time and its variance. Project duration can be reduced by incurring additional cost in executing activities. A project cost-time relationship can be obtained using Project crashing. This can also be used to obtain the optimal project duration. Resource allocation is one of the major problems in project management. A simple heuristic is suggested to handle this problem.

8.11 KEY WORDS

Projects: Set of activities which are inter-related with each other and are to be organised for a common goal or objective.

Activity: Physical independent action which requires time for its completion and will consume one or more of the resources.

Event: Point in time schedule at which an activity can be started (or is finished).

Activity Time: Physical time required to complete an activity.

Immediate Predecessor: An activity which should immediately precede the given activity in any feasible time schedule.

Project Network: A visual representation of the interdependence between different activities of a project.

Earliest Start Time: The earliest time at which an activity can begin. All the activities preceding the given activity should be completed by this time.

Latest Start Time: The latest time by which the activity can be started without delaying the project completion time.

Earliest Finish Time: The earliest time by which an activity can be finished.

Latest Finish Time: The latest time by which an activity can be completed.

Total Slack (float): The length of time up to which an activity can be delayed without affecting the start of the succeeding activities.

Free Slack (float): The length of time up to which an activity can be delayed without affecting the starts of the succeeding activities.

Critical Path: The longest sequence of activities or path in the project network. The time it takes to traverse this path is the estimated project completion time.

Critical Activities: Activities on critical path. Any delay in execution or start of these activities will delay the whole project.

CPM: Project management technique used when activity times are deterministic.

PERT: Project management technique used when activity times are probabilistic.

Optimistic Time: Time by which an activity can be completed, if everything goes well with it.

Pessimistic Time: Time by which an activity will get completed under adverse conditions.

Most Likely Time: Most frequently occurring time for an activity.

Expected Activity Time: The average activity time.

Variance: Measure of the deviation of the time distribution for an activity.

Crashing: The process of reducing an activity time by adding resources and hence usually increasing cost.

Normal Cost: Cost associated with an activity when it is completed in normal time.

Crash Cost: Cost associated with an activity when it is completed in the minimum possible time (crash time).

Resource Allocation Methods: Allocation of resources to the activities such that project completion time is as small as possible.

Updating: Revision of the project schedule after partial completion with revised information.

8.12 SELF-ASSESSMENT EXERCISES

- 1) Under what circumstances would you use PERT as opposed to CPM in project management? Give some example of projects where each would be more applicable than the other.
- 2) What do you understand by slack? Construct an example and show how you can use the knowledge of slacks for better project management.
- 3) Identify the information needed for the project crashing. For a project with which you are familiar, try to identify the various items of information. Criticise the various assumptions made in the crashing method.
- 4) Draw the complete CPM network according to the following table:

Activity	Starts at Event	End at Event
1-2	1	2
1-3	1	3
1-4	1	4
2-3	2	3
2-4	2	4
3-4	3	4

- 5) Draw the following logic network:
Activities C and D both follow A
Activity E follows C, Activity F follows D, E and F precedes B.
- 6) In putting a job together to run at a data-processing centre, certain steps need to be taken. These jobs can be described as follows:

Job	Time (minutes)	Immediate predecessors	Description
A	180	-	Design flow chart and write FORTRAN statements.
B	30	A	Punch control cards
C	20	A	Punch comment cards
D	60	A	Punch programme cards
E	10	B,C,D	Obtain brown folder
F	20	B,C,D	Put deck together
G	10	E,F	Submit deck

- a) Draw a critical-path scheduling diagram and indicate the critical path. What is the minimum time to completion?
- b) What is the free slack of job C?
- c) Assuming the table accurately represents the jobs to be done and their times, if you were performing this project, would the minimum time to completion obtained above be the minimum time for you also to complete the project. If yes, what conditions would change your answer? If no, why not, and what would the correct time be?

- 7) The following table lists a set of nine activities together with their sequence requirements, estimated activity times, and the daily number of men required for each activity. These nine activities make up a complete project.

Activity Code	Code of immediate Predecessor	Time Required (days)	Men Required per day
A	—	10	3
B	—	8	4
C	—	5	7
D	A	6	5
E	B	4	2
F	C	10	4
G	F	4	3
H	F	8	3
I	D,E,G	7	3

- Use this information to develop a network diagram.
- Determine the earliest start (ES), earliest finish (EF), latest start (LS), and latest finish (LF) times for each activity: '
- List the activities on the critical path.
- What is the earliest finish time of the project without resource constraints (assuming that we have an unlimited number of men)?
- Assume that we have only 11 men available but that each man is completely interchangeable. That is, any man can do any task. Also assume that the activities must use exactly the number of men and days specified. For example, you cannot use twice the manpower and complete the activity in one-half the time. Now determine (if possible) a schedule of activity starting times that will allow these 11 men to complete the project by the earliest finish date. If this is not possible, show a schedule that will finish the project as soon as possible with 11 men. (Start with day 1, not day 0).

8.13 FURTHER READINGS

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BLOCK-3

CAPACITY PLANNING, WORK AND JOB DESIGN & VALUE ENGINEERING

UNIT 9 Capacity Planning

UNIT 10 Work and Job Design

UNIT 11 Value Engineering and Quality Assurance

BLOCK 3 CAPAICTY PLANNING, WORK AND JOB DESIGN AND VALUE ENGINEERING

Unit 9 of the block discusses the concept of capacity, how it is measured and the various methods for predicting long term and medium term of capacity requirements. The next unit of the block deals with the problems of design of work methods, systems and procedures. Also the topics related to work and job design such as elimination of avoidable delays, work place layout, work measurement techniques and ergonomic considerations in job design and job enlargement etc have been explained briefly.

Unit 11 (Value Engineering and Quality Assurance) describes the major aspects of these topics of VE and Quality management. An attempt is made to develop appreciation of the role of VE in cost reduction and performance improvement. Some practical case studies are also touched upon to examine the improvements in product value through various skills and techniques of VE.

Quality Assurance explained later in the Unit 11 develops appreciation of the role of the quality control, quality assurance and quality assessment. Designing a sampling plan, drawing up operating characteristic curve (OCC) for a given sampling plan, computing average outgoing quality limit (AOQL) and assessing process variability that the process is in control or not also find adequate places in the subject matter of discussion.

UNIT 9 CAPACITY PLANNING

Objectives

After going through this unit, you should:

- understand the concept of capacity and how it is measured, be aware of the unique problems of capacity planning for services and know the steps involved in capacity planning.
- Be familiar with the various methods available for predicting long term capacity requirements, appreciate the special difficulties encountered in predicting the demand for new and other outputs having a highly uncertain growth rate and recognise the factors involved in generating alternate capacity plans.
- Have a feel for economic analysis of different capacity plans and identify the issues involved in analysing the strategic effects of alternate capacity plans.

Structure

- 9.1 Introduction
- 9.2 Meaning, Definition and Measure Of Capacity
- 9.3 Process for Capacity Planning
- 9.4 Predicting Future Capacity Requirements
- 9.5 Generation of Capacity Plans
- 9.6 Evaluation of Alternate Capacity Plans
- 9.7 Summary
- 9.8 Key Words
- 9.9 Self-assessment Exercises
- 9.10 Further Readings

9.1 INTRODUCTION

The operations strategy of an organisation is revealed to a large extent by its investments made in creation of capacity. Creation of capacity almost always requires investments. In manufacturing organisations this is easy to see as the investments required are large. However, even in service organisations, capacity creation requires more space, furniture and other accessories including equipment.

Capacity Planning involves giving shape to all the strategic questions that we have raised earlier in the previous units and also our response to these. What are our expectations regarding the growth of the industry and our market share? How accurately can we predict market trends, both in terms of product attributes as well as growth in specific segments — geographical and otherwise? What is our basic stand towards risks? Should our planning be based on an optimistic growth scenario or a pessimistic one? As a strategy,

should we create capacity in a few large locations, each with a large capacity or should we operate from many locations each with a small capacity? These are some of the questions that have to be answered while preparing a capacity plan.

There are some other related questions which also affect our capacity plans. What is our policy regarding making up of some temporary short-falls in capacity e.g. by use of overtime additional shifts or holiday work? How much of our requirement can be met by resorting to sub-contracting? What is our policy regarding meeting the market demand? Should we, as a matter of policy try to meet it fully or can we plan for some lost sales at least for some periods of time?

All these strategic issues need to be resolved as a part of capacity planning. It is relatively simple to do an economic analysis of the revenues, costs and investments. However, the other strategic effects of capacity decisions-e.g. the consequences of not having the capacity when it is required or addition of large capacity when the market growth cannot be predicted with much confidence, are more difficult to analyse. We will discuss these issues in this unit.

9.2 MEANING, DEFINITION AND MEASURE OF CAPACITY

Capacity is the limiting capability of a productive unit to produce within a stated time period and this limiting capability depends on the intensiveness of use of productive unit. For Example by working for seven days a week instead of six or resorting to overtime work or working for two shifts a day, or even three in place of one, the capacity of a productive unit can be increased.

When the transformation process in turn consists of many sub-processes, the capacity of the system is governed by the capacity of the weakest link of the subprocess having the minimum capacity.

By strengthening the weakest link by “balancing equipments” or by subcontracting of some items, the capacity of the entire productive unit can be enhanced.

Thus there can be a **licensed capacity** denoting the capacity that has been licensed or permitted by the concerned governmental authorities. The **installed capacity** indicates the capacity that has been provided while the plant was installed and finally the **rated capacity** is based on the highest production rate established by actual trials.

Rough-cut capacity planning is the process of checking the feasibility of the master schedule with respect to the available capacity.

Measure of Capacity

When the productive unit produces a single output and when the different outputs are relatively homogeneous, capacity is measured in number of units/unit of time. The capacity of some of the manufacturing units and

service organizations are shown below :

Capacity of a textile mill	Meters of cloth length/day.
Capacity of a plywood factory	Square meter of area of plywood of fixed thickness/day
Capacity of makers of mineral water and soft drinks	Litres of liquids/day
Capacity of oxygen or gas manufacturer	Cubic meters/day at specified temp, and pressure
Capacity of an automobile organization	Number of vehicles/month
Capacity of a thermal power plant	Megawatt of energy/unit time
Capacity of a job shop producing product as per customers need.	Available units of limiting resources/day
Capacity of a hospital	Number of bed days/month
Capacity of a school	Number of students in one class per semester
Capacity of a consultancy organization	Number of consultation day per year
Capacity of an insurance company	Number of insurance policies serviced per year
Capacity of a bank branch	Manhours per week
Capacity of a trucking company	Tonnes-kilometer per day.

9.3 PROCESS FOR CAPACITY PLANNING

Capacity planning is a process that helps to identify the capacity of a production unit that is required for meeting the current and future customer demands.

The design capacity of a system is the rate of output of goods and services under full scale operating conditions. The operations strategy of an organization is revealed to a large extent by its investment made in creation of capacity. In manufacturing organization, the creation of capacity requires a huge investment and even in service organizations it requires a good investment for more space, furniture and other accessories including equipment. The strategic issues regarding the capacity planning are:

Our expectations regarding the growth of industry and our market share, accurate prediction of market trends, should we operate from a few large locations each with large capacity or should we operate from many locations each with a small capacity, how much of our requirements can be met by the use of overtime, additional shift or holiday work or by the use of subcontracting etc.

The process for capacity planning involves the following eight steps:

- 1 Assess company situation and environment to predict future demands, including the possible impact of technology, competition and other events
- 2 Determine the available capacity
- 3 Translate predictions into physical capacity requirements
- 4 Develop alternate capacity plans for matching required and available capacity
- 5 Analyse the economic effects of alternate capacity plans
- 6 Analyse the risks and other strategic consequences of alternate plans
- 7 Recommend a course of action
- 8 Implement the course of action.

It may be pertinent to point out that a quantitative analysis of the alternate capacity plans is not enough because, for one, the capacity requirements that are used for this analysis are only estimates and in many cases may not be very reliable and secondly, the strategic effects are not easy to quantify in most cases. The steps listed above highlight the importance of both quantitative (step 5) and qualitative (step 6) analysis.

9.4 PREDICTING FUTURE CAPACITY REQUIREMENTS

Mature Outputs with Stable Demand Growth

Outputs which are in the maturity phase of their product life cycles exhibit less volatility in their demands. In the event of the life cycle being long, the demand growth is steady and the demand can be predicted with great accuracy and confidence. Such outputs being steel, cement, sugar, salt, electricity, textile, municipal services and hospital services etc.

Long term and medium term forecast of the demand of an output are made by using the following causal forecasting methods.

- (i) **Regression Analysis** : It attempts to develop a forecasting function called a regression equation in which the demand for the output is expressed in terms of other variables which cause or control the demand. For example demand of tyres, tubes and batteries may be expressed as a function of number of automobile vehicles sold, demand for furniture may be expressed as a function of new construction activities, new marriages performed during the year and disposable personal income during the year etc. It requires considerable time and cost as various hypotheses regarding the effect of variables may have to be tested to develop the regression equations.
- (ii) **Econometric Forecasting Method** : These being an extension of regression analysis include a system of simultaneous regression equations. For example the demand of a product can be expressed as a

function of GNP, price and ads. The price in turn is a function of its cost, selling and distributing expenses and profit; the cost may be a function of production and inventory levels and finally the selling costs. Instead of one relationship, there are four now which are to be estimated simultaneously. These methods require high amount of time and cost.

(iii) **Delphi Method** : It is a forecasting technique (qualitative method) applied to the subjective nature of demand values. This method draws upon a panel of experts in a structured manner to eliminate the possible dominance of the more vocal, more prestigious and the better salespersons in the group. The essential precautions to be followed in this method are

- (a) Panel members must be unknown to each other.
- (b) The initial questionnaire should be unambiguous.

Also it should explain every matter about which opinion is sought. Each expert in the group makes independent prediction in the form of brief statements. The coordinator edits and clarifies these statements and then provides a series of written questions to the experts along with the feedback by the other experts. This process is continued for several rounds, A reasonable amount of convergence is, however, achieved in usually three to four rounds.

Thus Delphi technique is a formal, structured method to lead a panel of experts to a consensus rather than a compromise by providing feedback in written form and by eliminating the possible dominance of influential members.

(iv) **Market Survey** : Market surveys and other studies on customer behaviour provides us with a lot of primary data on the factors such as :

- (a) What makes the customer buy the product.
- (b) What features have a high priority in customers' preference structure.
- (c) What are the perceptions of the competing products.
- (d) The likely impact of price changes.
- (e) What are the changes to be incorporated in the product etc.

Such insights can prove to be extremely useful while the long term demand of the product is being predicted.

(v) **Historical Analogy and Life Cycle Analysis** : These try to predict the growth of demand of a product by analysing its progress so far along its product life-cycle and also by comparing if the life-cycle of another similar product. For instance, the growth of demand of colour TV sets can be compared with the life-cycle of B/W TV sets and long term prediction of colour TV sets can be made based on such comparison. Similarly for CFL vs traditional electric bulbs and CD vs cassettes.

In case of multiple outputs, a similar exercise is to be undertaken for each of them and when added, they provided the capacity required throughout the planning horizon. If the outputs are not homogeneous, this might mean different capacity requirements for each sub-process.

Predicting future Capacity Requirements for New Outputs

To prepare reliable long term demand forecasts for new products in their introduction or even through rapid growth phases is a very difficult task. This is also true for some mature products where the capacity planning is dependent on availability of supplies and this could be risky- for example for petroleum. As the uncertainty involved in such cases is higher, we should try to take into account the probability distribution of demand. We should attempt to prepare an optimistic prediction of demand as also pessimistic prediction of demand along with expected predicted demand. If the optimistic predictions come true, then large capacity editions have to be built and the process has to start immediately. On the other hand if the pessimistic predictions come true, then the capacity editions need to be much smaller and slower. In between is the expected predicted demand

9.5 GENERATION OF CAPACITY PLANS

Once the capacity requirements have been worked out, alternate capacity plans, listing the size and timing of capacity additions, can be generated. If the capacity available does not match the capacity required in any year, the capacity plan also mentions whether alternate sources of capacity will be used or whether the plan is prepared with the possibility of lost sales.

Size of Capacity Increments

When there is a growth in predicted demand of a product, the important question is how much of capacity has to be added and when. Two strategies for capacity addition could be easily formulated: (i) add capacity in small increments but more often, and (ii) add large capacity increments but less often.

Two other related options are: (i) add capacity before the requirement exceeds the capacity available, and (ii) add capacity after the requirement has overtaken the available capacity. Of course, one can have mixed options such as adding a large capacity increment so that the available capacity is much in excess of the likely demand. However, as the demand is continuously growing, it will soon overtake the available capacity and then add another large increment of capacity.

Alternate Sources of Capacity

We have seen above the capacity of any facility also depends on the intensiveness of use. Therefore, a manager has access to a higher capacity without really building additional capacity by increasing the intensiveness of use. This includes alternatives like overtime, holiday work and additional shift working, etc. There is a further possibility of subcontracting a part or all of the transformation processing to outsiders and have access to their

capacities as well. However, for specialised and sophisticated processing, subcontracting may not be feasible and similarly, for process industries working round the clock, it may not be possible to increase the intensiveness of use.

By making use of these alternate sources of capacity, one can reduce the cost of carrying a high capacity along with reducing the risk of not using the capacity built. Alternate capacity plans may have capacity gaps which would be met from these alternate sources of capacity.

Cost-Volume Relationships

For a given capacity, unit cost of production decreases with higher volume as the fixed cost gets spread over a larger volume. However, near the capacity limit and marginally above the normal capacity, the unit cost increases as the variable cost per unit starts increasing due to higher costs involving overtime, holiday work, subcontracting, etc. as well as the effect of general congestion at work places and of equipment. In effect, therefore, the unit cost of production will have the shape of a 'U' with the minimum being somewhere near the normal capacity established.

Economies of Scale

A higher capacity plant offers some economies of scale. It is worthwhile going in for greater automation only in a high capacity plant. This, coupled with more sophisticated technology enables, a larger capacity plant to produce at a lower variable cost per unit although the fixed cost of production is much higher. The combined effect of these is that a lower unit cost can be achieved in a larger capacity plant.

There are other economies of scale as well. With increase in capacity, the increase in investment in inventories is less than proportional e.g. a 100% increase in capacity would require an increase of about 40%--50% in investment in inventories giving rise to an economy of scale. Similarly, in many process industries, the capacity increases as per the volume of pressure vessels, pipes, tanks, etc. where as construction costs vary as per the surface area of the same giving rise to an economy of scale in construction costs.

Lost Sales

An alternative to meeting the capacity requirement through additional capacity or alternate sources is to absorb some lost sales. However, lost sales always amount to losing some market share. This is a very risky alternative, especially in the face of competition, while generating capacity plans because market share losses could be permanent.

Although lost sales are not found in capacity plans of commercial organisations, capacity could be perennially found to be below the requirement in case of many infrastructural facilities. This could be seen in power, public transportation, telephones, water supply and other, facilities. Even for commercial organisations, when there are sudden spurts in demand growth, there may be no alternative to meeting the demand through lost sales which amounts to absorbing a loss in possible contribution.

Multiple and Anticyclic Outputs

As mentioned above, multiple outputs increase the stability of demand growth. Each output being in a different phase of its respective product life cycle, the demand for some outputs shows decline that of others could be in their growth phases. Consequently, the overall capacity requirement will have much less fluctuation than that for any one output.

A similar concept is useful even when the demand for an output is highly seasonal and varies widely during the course of a year. If possible, the addition of an anticyclic output can help in stabilising the capacity requirement throughout the year. The demand for electric fans is highly seasonal with the peak occurring in summer and the sales in winter coming close to nil. If heat convectors, which require similar production process, are added to the product range, the capacity requirement throughout the year will be more stable as the demand for heat convectors peak in winter. Electric fans and heat convectors are therefore anticyclic and the addition of anticyclic outputs makes it possible to have better capacity plans.

9.6 EVALUATION OF ALTERNATE CAPACITY PLANS

The alternate capacity plans developed will have to be analysed to find the one which is most desirable for our purpose. This involves a quantitative analysis to find the economic consequences of different capacity plans based on the assumptions made regarding what is going to happen in future. However, there are uncertainties regarding future as well as many strategic effects flowing from capacity plans all of which cannot be quantified precisely. That is why there is a need for quantitative assessment of the risks and other, strategic consequences.

Economic Analysis for Mature Outputs with Stable Demand Growth

Establishment of capacity is always an investment and the returns from it accrue over a period of time. That is why some kind of discounted cash flow analysis has to be used so that alternate capacity plans can be compared.

For each alternate capacity plan, the general procedure requires that all the cash flows occurring indifferent years upto the planning horizon have to be listed. All the costs incurred are cash outflows and the revenues earned are cash inflows. When all these cash flows are discounted at the cost of capital for the enterprise, we get the Net Present Value (NPV) for each capacity plan. The capacity plan having the highest NPV will be the most attractive from an economic perspective.

This basic methodology can be expanded by adding to the list of alternative capacity plans to take care of different locations e.g. when considering capacity expansions and even plans to have vertical integration — both backward (to produce what we are buying from our suppliers) and forward (to use in further processing and assembly what is currently our finished product).

Economic Analysis for Outputs with Highly Uncertain Demand Growth

When the demand growth is highly uncertain, the consequent cash inflows from any capacity plan are not reliable enough to make any conclusions. In such a case, knowledge of the probability distribution of demand is quite useful and in the absence of the detailed distribution, one needs to know the optimistic, expected and pessimistic predictions of demand. For each of these scenarios, the NPV for each alternate capacity plan can be computed. Different and appropriate capacity plans can turn out to be the most economic under each of these scenarios.

A more formal approach for such a situation involves using a decision tree to analyse the various alternate plans. Both the alternatives and the uncertain outcomes are shown on the decision tree. Probabilities are assigned to each of the uncertain outcomes and finally, the tree is folded back to find the best capacity strategy which results in the highest value of some criterion like the expected NPV. When the demand growth is highly uncertain, the choice of a capacity plan is highly dependent on the strategic effects of having, an over or an under-capacity.

Risk Analysis of Alternate Capacity Plans

All capacity plans are based on prediction of probable demand and the future can never be predicted exactly. Thus, there is always some element of risk present in any planning process. What we have said above is that the risks are higher in the case of new outputs than in the case of mature outputs with stable demand.

If demand cannot be predicted exactly, the actual demand will either be low or higher than the predicted demand. In the first case, we are likely to be burdened with over capacity and in the second event we are likely to suffer from an under capacity. We should analyse the likely consequences of both overcapacity and under capacity.

In each of the following situations the organisation may plan for having an overcapacity rather than an undercapacity if: (a) there are some minimum economic capacity sizes, below which the process becomes uneconomic, (b) the cost involved in establishing capacity is relatively low, (c) subcontracting is very difficult or impossible, (d) the lead time required to establish new capacity is very long, (e) the demand growth is more likely to be nearer the optimistic prediction than the pessimistic one, (f) cost sales are perceived by the trade very negatively and may amount to a more than proportionate drop in market share.

On the other hand, the organisation may plan to add capacity on a conservative basis in each of the following situations if: (a) alternate sources of capacity are easily available, (b) the cost involved in establishing capacity is relatively low, (c) the lead time required to establish new capacity is relatively short (d) the customers are either expected to wait or the lost sales have no long term consequences if the demand cannot be satisfied.

It is difficult to quantify many of the strategic consequences from having an undercapacity or an overcapacity and what is important is to assess how these influence the competitive ability of the organisation.

9.7 SUMMARY

We have looked at the process of capacity planning in an organisation in this unit.

We defined capacity as the limiting capability of a productive unit to produce. In case of homogeneous, outputs, the capacity can be expressed in units of output per unit of time. However, when the outputs are not homogeneous, the availability of the limiting resource is used to measure capacity.

We have listed an eight step process for capacity planning. One of these relates to the prediction of demand in future. We have discussed some of the methods available for long-term demand prediction which can be used for prediction of demand of mature outputs with stable demand growth. On the other hand, we need to assess the probability distribution of demand in future for new outputs and others where the demand growth is highly uncertain.

While generating alternate, capacity plans, the two primary factors are the size of capacity additions and the timing of such additions. It is necessary to know the alternate sources of capacity, cost-volume relations, economies of scale and the effect of lost sales while generating capacity plans.

Both quantitative and qualitative analyses have their role while analysing the alternate capacity plans recommended for implementation. While quantitative analysis looks at the direct economic consequences emanating from a capacity plan, qualitative analysis evaluates the strategic consequences of ending up with over and under capacity.

9.8 KEY WORDS

Alternate Capacity Sources: Sources which increase the normal established capacity of any productive unit by increasing the intensiveness of its use e.g. by using overtime, holiday work and additional shift, etc. or by subcontracting the whole or a part of the processing.

Capacity: The limiting capability of a productive unit to produce.

Capacity Gap: The shortfall in capacity available to meet the capacity requirement.

Delphi Technique: Delphi Technique (named, after the place Delphi in ancient Greece where the technique was first experimented in late 1940s by Rand Corporation) is a formal, structured method to lead a panel of experts to a consensus rather than a compromise by providing feedback in written form and by eliminating the possible dominance of vocal, prestigious members.

Econometric Forecasting Methods: An extension of regression analysis to include the estimation of a system of simultaneous equations.

Economies of Scale: The reduction in unit cost achieved by employing a higher capacity plant due to lower variable cost per unit from more sophisticated technology, lower capital costs per unit of capacity, lower investment in inventories per unit of capacity etc.

Life Cycle Analysis: Predicting the demand growth of an output by comparing its growth with the product life-cycle of a similar output.

Lost Sales: The excess of demand over the capacity available, which amounts to a loss in contribution and might lead to a permanent fall in market share.

Market Surveys: Surveys of different elements of the market, e.g. customers, dealers and traders etc. to find facts and attitudes towards an output or any of its characteristics.

Mature Output: An output in the maturity phase of its product life cycle.

Regression Analysis: A statistical method used in forecasting with the help of a regression equation which expresses the demand in terms of other variables which presumably control or cause the sales to increase or decrease.

Strategic Effects: Long-term effects of any decision which can influence the ability of the organisation to exist or to grow.

9.9 SELF-ASSESSMENT EXERCISES

- 1 What is meant by intensiveness of use of a productive unit and how is it relevant while establishing its capacity?
- 2 Service Organisations usually have to be provided with a higher capacity than the annual or monthly requirement. Why?
- 3 What do you think are the appropriate methods for predicting future requirements for the following?
 - i) Cement
 - ii) Colour television sets
 - iii) Pre-cooked noodles
 - iv) Petroleum
- 4 Establishing a minimum capacity and managing with alternate sources like overtime, additional shifts, and subcontracting is always a low-risk strategy. Comment.
- 5 Electronic toys are slowly becoming popular in the Indian market. The manufacturing process is relatively simple and primarily involves the assembly of many bought-out components. Assembly capacity can be added in relatively small units and is not very expensive as the assembly operations are highly labour intensive. Formulate a capacity plan for five years for such a unit of electronic toys.

- 6 What do you understand by 'capacity'? Differentiate between licensed capacity and rated capacity of a plant.
- 7 Discuss briefly with suitable examples each of the following;
 - a) A long range capacity decision.
 - b) An intermediate range capacity decision.
 - c) A short range capacity decision.
- 8 Formulate a capacity plan for ten years for a company manufacturing and marketing cellular phones.
- 9 How do the capacity considerations in a hospital, automobile service centres and a company making lawn mowers differ? Explain
- 10 State whether the following statements are true or false
 - a) There are no useful quantitative forecasting models for long-term prediction of future requirements (True/False)
 - b) For mature outputs with stable demand growth, the capacity gaps are uniform across all departments or sub-process. (True/False)
 - c) In some situations, absorbing lost sales could turn out to be more economical than installing new capacity. (True/False)
 - d) It is more economical to plan capacity addition in small increments and more often, than to have large capacity additions and less often. (True/False)

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UNIT 10 WORK AND JOB DESIGN

Objectives

Upon completion of this unit, you would be able to:

- relate the reasons and objectives for studying Work Design, identify the need for an integrated approach to Work Design, understand that Work Study is one of the productivity improvement techniques chosen for achieving objectives of work Design and realise that the approach is essentially a scientific, systematic method of problem solving.
- conduct Methods Studies, Time Studies and Work Sampling with a fair degree of confidence, detect certain factors that have not found a place in this unit, though they are also of prime importance to Work Design and realise that concepts discussed in the unit are not necessarily restricted only to manufacturing situations.
- establish the complementary nature of job design to work design, understand the relevance and importance of ergonomics and human engineering to job design, realise the need for considering appropriate design considerations for improving productivity and realise the need for providing a good environment and workplace.
- realise the need for providing appropriate rest pauses during work hours, understand the relevance and importance of behavioural dimensions of job design, identify the need for adopting a socio-technical approach to job design and appreciate that appropriate work and job design together would go a long way in realising a better quality of life.

Structure

- 10.1 Introduction to Work Design
- 10.2 The Work Study Approach
- 10.3 Method Study
- 10.4 Work Measurement
- 10.5 Work Study Application
- 10.6 Introduction to Job Design
- 10.7 Design Factors
- 10.8 Environmental Factors
- 10.9 Organisational Factors
- 10.10 Behaviour Dimensions of Job Design
- 10.11 Socio-Technical Approach to Job Design
- 10.12 Summary
- 10.13 Key Words
- 10.14 Self-assessment Exercises
- 10.15 Further Readings

10.1 INTRODUCTION TO WORK DESIGN

Work Design is a systematic investigation of contemplated and present work to formulate through the ideal system concept, the easiest and most effective technique for achieving necessary goals. **Job Design** is a function of specifying the work activities of an individual or group in an organization to develop job structures meeting the need of the organization and satisfying the job-holder's personal requirements.

For most of us, work is a major source of economic livelihood and human enrichment. Everyone works. The attitudes towards work held by various individuals and different societies keep changing at various times in human history. In defining the work system, we could set boundaries to what must be effectively and efficiently managed. A work system brings together technical competence in the form of people and equipment to achieve the organisational objective. **Work Design is concerned with the study and design of work system in any type of organisation or institution.**

Historical Trends in the Management of Work

From the beginning of mankind, individuals or groups of individuals have engaged themselves in a multitude of activities with a progressive degree of sophistication and ingenuity to satisfy their basic needs and wants. Over the years, the effort has been to provide work and time saving devices, some of which have resulted from flashes of genius and long experience rather than from any degree of systematic study of work.

The scientific method of work design produced its greatest achievements in the mass production assembly lines of the post World War I phase. Man was viewed as an extension of the machine or rather as an element or cog in a complex production system dominated by costly equipment. The primary emphasis was on profit, concern for streamlining operations, eliminating waste, and financially motivating the workers to increase output and productivity. Industrial engineers employed a machine theory of man to study and design work, concentrating primarily on the technological side of work resulting in a highly standardised, economically efficient form of work. On the other hand, the social scientists were equally concerned with work design aspects from the behavioural angle. Technologically, work is seen in terms of the tools, techniques and methods used for production of finished goods. Economically, work has come to be associated with paid employment

Work Design for Increased Productivity

The continued progress of any enterprise is dependent on its ability to optimally and judiciously allocate and utilise its resources so as to provide desired products and/or services at the right time, place, price, quality and quantity to the community. This requires an integrated approach. Efficiency and effectiveness spring from unity of purpose and the application of the right principles to a given situation. The effort of any enterprise should be to raise

productivity and reduce wastivity, so as to ensure a higher standard of living, greater purchasing power and an enhanced human dignity. This 'total spiral pattern' of movement would hopefully lead to a better 'quality of life'. Taylor had illustrated that high levels of productivity result in more quality goods at lower costs which is the basis for lower prices, higher purchasing power and real earnings, improvement in working and living conditions and sometimes even shorter working hours (and hence perhaps more leisure).

All organisations need increased productivity. They must continually seek better and less expensive ways to perform their functions/tasks if they hope to survive in an increasingly competitive and quality conscious economy. It is hoped that increasing the effectiveness of accomplishing work reduces the actual cost of the work, which makes the resulting product and/or service available to more individuals which in turn increases the demand for work and, hopefully leads to generation of work and employment. In fact, productive activities are the primary source of material benefits. These benefits from increased productivity are shared by employees, managers, owners, entrepreneurs, consumers and society at large. There are non-material benefits also which might, after a stage, assume greater importance. We would leave some of these aspects to be discussed in 'Job Design' and go on to discuss the Work System Design in the belief that work exists and it would have to be done.

The Work System Design

Work problems do not exist without work. Work does not exist without the desire to render a service or manufacture a product which is needed by someone, somewhere, at some time. Certain resources like men, machines, materials, money, methods and management are to be so organised as to produce the desired output effectively and efficiently. Work problems usually originate within the individual work station.

However, the man-material-machine combination, which is at the centre of almost every work problem, is only a part of the entire organisation or work system which itself is a part of yet a larger super system. Most work systems or sub-systems are essentially open systems. Therefore, there is a great deal of complexity in the forces of interaction and reaction. The magnitude of these 'forces' is determined by the value structure associated with the work system. The quantifiability and even adequate identification of these forces is rather difficult. The systems conceptualisation is ideal but sometimes impregnable. In addition to system is the 'method' which is also important in Work Design.

In fact Work Design is the systematic investigation of contemplated and present work systems to formulate through the ideal system concept, the easiest and most effective systems and methods for achieving necessary functions/goals/purpose. Nadler proposes the following five Work Design assumptions or philosophies:

- 1) Increasing productivity and developing manpower effectiveness are the objectives for studying work system.
- 2) Work systems can be encountered in three states or conditions — design, betterment and improvement.
- 3) All aspects of the work system, regardless of the system level, are to be considered in Work Design.
- 4) People, their abilities, and talents are an integral part of Work Design. This results from the recognition that people, at all levels, can really understand many of even the most involved techniques and situations.

Work Design does not advocate the use of any particular set of techniques. Work systems and their components are to be studied continually. Since a system involves a multitude of components, it would appear that each function of the enterprise, through its specific systems, would take a segregated part of the total project or study, and accomplish its function within the framework of its specific objectives, for increased productivity and higher effectiveness. Among the numerous techniques available for enhancing productivity, one is **Work Study** which is perhaps one of the most popularly used techniques. No doubt, the success of the technique lies in its simplicity as well as the method and scope of its application. It cannot possibly exist in a vacuum. It must be part of an overall programme with due support from management and employees, that encourages increased productivity for specific reasons so as to finally provide a higher standard of living, human dignity and quality of life.

10.2 THE WORK-STUDY APPROACH

Work study is indeed an important tool for achieving higher productive efficiency of an organisation in a scientific manner.

Work study is a generic term for those techniques, particularly method study and work measurement which are used in the examination of human work in all its contexts, and which lead systematically to the investigations of all the facts which affect the efficiency and economy of the situation being reviewed, in order to effect improvement.

Method study: The systematic recording and critical examination of existing and proposed ways of doing work as a means of developing and applying easier and more effective methods, and reducing costs.

Work measurement: The application of techniques designed to establish the time for a qualified worker to carry out a specified job at a defined level of performance.

The main objective of work study is to improve the effectiveness of important parameters of production such as men, machines and methods.

Method study and Work measurement are closely linked. Method study is concerned with reduction of the work-content of the operation, while Work measurement is concerned with the investigation and reduction of the ineffective time and the subsequent establishment of time-standards for the operation on the basis of the work content as established by Method study. Usually a method study should precede work measurement. However, when time-standards for output are being set, it is often necessary to use one of the work measurement techniques like work-sampling in order to determine where ineffective time is occurring and its extent so that management action can be taken to eliminate it even before going in for method study. Equally, on the other hand, time study may be used to compare the effectiveness of alternative methods.

Basic Work Study Procedure

There are eight basic steps, some of which are common to both method study (MS) and work measurement (WM)

- 1) Select (MS and WM)
- 2) Record (MS and WM)
- 3) Examine (MS and WM)
- 4) Develop (MS)
- 5) Measure (WM)
- 6) Define (WM)
- 7) Install (MS)
- 8) Maintain (MS)

However, good relations must be established before conducting a work study. There must be top management support apart from good cooperation from the supervisors/ foremen, who must be sounded about the utility of conducting the study. All instructions and questions should preferably have the supervisors 'green signal'.

Contrary to the widely held belief, work study, properly applied, tends to improve industrial relations. The workers feel happy that a member of management takes the trouble to come to them to discuss about their job and problems. Do not conduct the study amidst distrust and suspicion. Try to win the confidence of all concerned. There could usually be strong resistance to change in working methods by the set of older skilled workers. Moreover, employees may be concerned with redundancy arising out of the results of work study, leading either to unemployment or transfer to some other department or work station elsewhere. This is perhaps one of the greatest fears in a developing country such as ours. This argument is very much like the ones criticising the advent of the Industrial Revolution, the age of high mechanisation and now the Hi-Tech process of rapid computerisation. Let us learn from history to welcome these developments for the ultimate good of people in the long run.

A work study person should have at least a good secondary or preferably a graduate education. It is desirable that he has some actual on-the-job work experience.

Practical experience will make the work study analyst command respect from the employees/subjects being studied and also the supervisory personnel. A work study person should have sincerity, honesty, enthusiasm, interest in and sympathy for people, tact and self-confidence. Though it is difficult perhaps to find a person with all these qualities, at least the work study person must have the ability to deal with people. It will be seen that the results of work study, however scientifically arrived at, require to be applied with 'art' just like any other management technique.

Having given a basic overview of work study, we can now go on to discuss method study, primarily concentrating on the steps involved with a view to raising effectiveness and productivity. We shall be skipping over some details of physical environment, therbligs, principles of motion economy, etc. which are to be included in the following unit, while discussing various aspects of Job Design.

10.3 METHOD STUDY

You will recall from the previous section that the techniques of method study aim essentially to do three things:

- reveal and analyse fully the facts concerning any situation
- examine the facts critically
- develop from the examination of facts, the best possible answer under the circumstances.

The findings of method study should definitely result in better utilisation of manpower and other tangible resources. It would also have identified bottleneck activities and initiated necessary action to minimise, if not totally, eliminate, the bottlenecks. However, while making suggestions for improvements, economy in human effort, the reduction of unnecessary fatigue and the development of a better physical working environment should be taken note of. Some of these aspects have been discussed in the following unit on Job Design

Method study in its generalized field of activity can also be termed as work simplification.

The following section deal with it in a definite and ordered sequence of defferent a definite and ordered sequence of different stages as under:

- i) Ideatification
- ii) Recording
- iii) Examination
- iv) Development

Identification

As mentioned above, the first stage is the selection of work to be studied which is primarily based on:

- a) Economic considerations
- b) Technical considerations
- c) Human considerations.

Economic considerations are important. The obvious areas of application of method study are bottlenecks, excessive movement, operations involving repetitive work, excessive work in process and unsafe work conditions.

The most important thing in technical consideration is to ensure availability of relevant technical knowledge with which to make the study. Human considerations and reactions, need to be accounted for too. Method Study, will be more readily accepted if the first subjects/jobs are the unpopular ones such as dirty jobs having many allied unpleasant features. If the study improves these type of jobs by reducing unpleasantness, effort and fatigue, then method study/work study will be welcomed. If however, the study of a particular job appears to be leading to unrest or ill feeling, then leave it alone and wait for an appropriate time or switch over to alternative subjects.

Fig. I: Conventional Systems and Definitions of Activities used in Work Analysis

Standard symbol	Name of Activity	Definition of activity
O	Operation	An operation occurs whenever something is produced or a task is accomplished . An object is intentionally changed in any of its physical or chemical characteristics, is assembled or disassembled from another object. An operation also occurs when information is given or received when planning or calculation takes place. Operations could be 'do' type, 'make ready' type or 'put away' type.
➔	Transportation	A transportation occurs when an object is moved from one operation to another, from one place to another, except when such movements are a part of the operation or are caused by the operator at the work station during an operation or an inspection.
□	Inspection	An inspection occurs when either a qualitative or quantitative appraisal or verification is made.

D	Delay	A delay occurs to an object when conditions except those which intentionally change the chemical or physical characteristics of the object, do not allow or require immediate performance of the next planned step. It is essentially a temporary storage which describes a state of inactivity and has an interference effect.
▽	Storage	A storage occurs when an object is kept and protected against unauthorised removal. The difference between storage and delay is often a fine one, e g. material is formally committed to storage but is informally delayed.
□ ➔	Combined Activity	A combined activity occurs when two activities occur simultaneously. Various combinations of simultaneous occurrence of two activities could be possible.

After selecting the work to be studied and before actual commencement of the subsequent steps, it is important to decide on the objectives to be attained, in order of priority. With the objectives for the study in mind, it will then be possible to consider the degree of detail that should be gone into. Clearly, no study should be more detailed than is justified economically, and so the selection of a job must be based on an estimate of time and expense needed.

Recording

When a job has been selected and the detail and extent of the investigation decided, the systematic analysis of the work is begun. A record is to be made of all the relevant facts relating to the present method which would have to be subjected to a critical examination. But before that let us discuss the models of sequence or flow of work which are best understood by most persons when presented pictorially.

Need for graphical methods/charts

Most people find the graphical or pictorial representation of information invaluable when they are faced with a mass of facts that they must study systematically, because there is less chance of overlooking any detail. Many types of charts and diagrams form a vital part of the 'Recording stage' in 'work study, especially while conducting method study'. It is preferable to adhere to standard conventions of charting shown in Figure I, so as to enhance its utility in recording, examining and development stages. Let us now discuss some charts which would be particularly relevant for work study.

- a) **Chronological sequence analysis:** In this case, break down the process under study into events or activities chronologically. There could be product/material- oriented process charts or person-oriented process charts.

In process charts, a sequence of events is portrayed diagrammatically by means of a set of process chart symbols to help a person visualise a process as a means of examining and improving it.

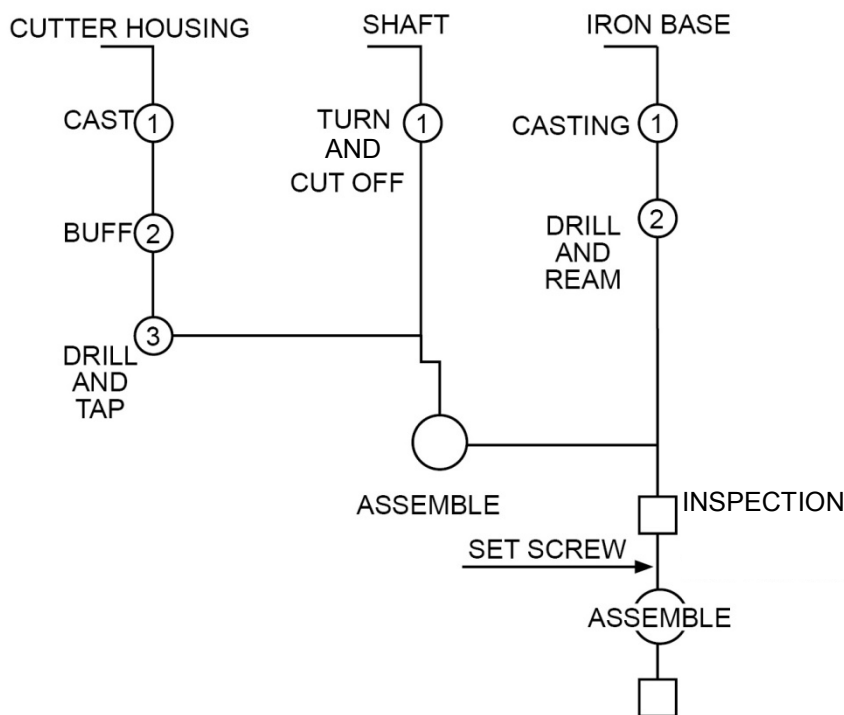


Fig. II: Operation process Chart

An operation/outline process chart: Figure II is the one giving an overall picture by recording in sequence only the main **operations** and **inspections**. Only the major events such as principal operations and inspections are recorded. It provides an overall view, a quick idea of the entire process from beginning to end at a glance.

A more detailed type, highly developed version of process charts is the **flow process chart** which is a graphic representation of the chronological sequence of all **operations, transportation, inspections, delays** and **storages** occurring during a process or procedure, and includes information considered desirable for analysis such as time required and distance moved, etc. There could be the following types of flow process charts:

- i) Material or Product type, Figure III which records what happens to material/product.
- ii) Man type which records what the worker/operator does.
- iii) Equipment type which records how the equipment is used. The equipment type chart is similar to the product/material type chart.

SR NO.	ACTIVITY DESCRIPTION	○	□	▽	D	⇒	REMARKS
1.	Costing lying in the foundry store			●			
2.	Moved to cutting – machine					●	Trolley used Distance moved 20 meters
3.	Wait, cutting machine being set.				●		
4.	Riser cut	●					
5.	Wait for trolley				●		
6.	Moved to machine shop					●	Trolley used Distance moved 15 meters
7.	Inspect before – machining		●				
SUMMARY							

Fig. III: Flow Process Chart (Material)

The flow process charts are usually either of material or man or equipment type. But in some cases it could be possible to develop a combined flow process chart for triple resources involving a person, material and equipment.

There is yet another type of flow process chart called a **form process** chart which is a graphic symbolic representation of the process flow of paperwork form. In this case the item of interest is one or more forms. Such a chart may show organisations, operations, movement, temporary and controlled storage, inspection or verification, disposal of all forms charted, and the source and type of information transmitted between forms. Perhaps such form process charts are more useful in Organisation and Methods (O&M) Studies which are applications of work study in offices.

Then there could also be **two-handed** process charts (Figure IV), in which the activities of a Worker's/operator's hands (or limbs) are recorded chronologically to one another. Somewhat similar to the above types of charts are the **multiple activity** charts (Figure V) where the activities of more than one subject (worker, machine or equipment) are recorded on a common time scale to show their inter-relationship.

- a) **Movement and Flow of Activities:** Process charting helps to visualise the sequence of events in a situation but it cannot illustrate the pattern of movement that men, materials and tools have to follow when a job is being done. Here we find that certain types of diagrams are helpful to indicate visually the path of movement.

One such type of diagram is the flow diagram Figure VI. In its simplest form, it should show a rough (or scaled) view of the space, which shows the location of specific activities carried out, the extent of work areas, machines, or desks, with

a connecting set of arrows and lines to indicate the routes of travel followed by workers, materials or equipment.

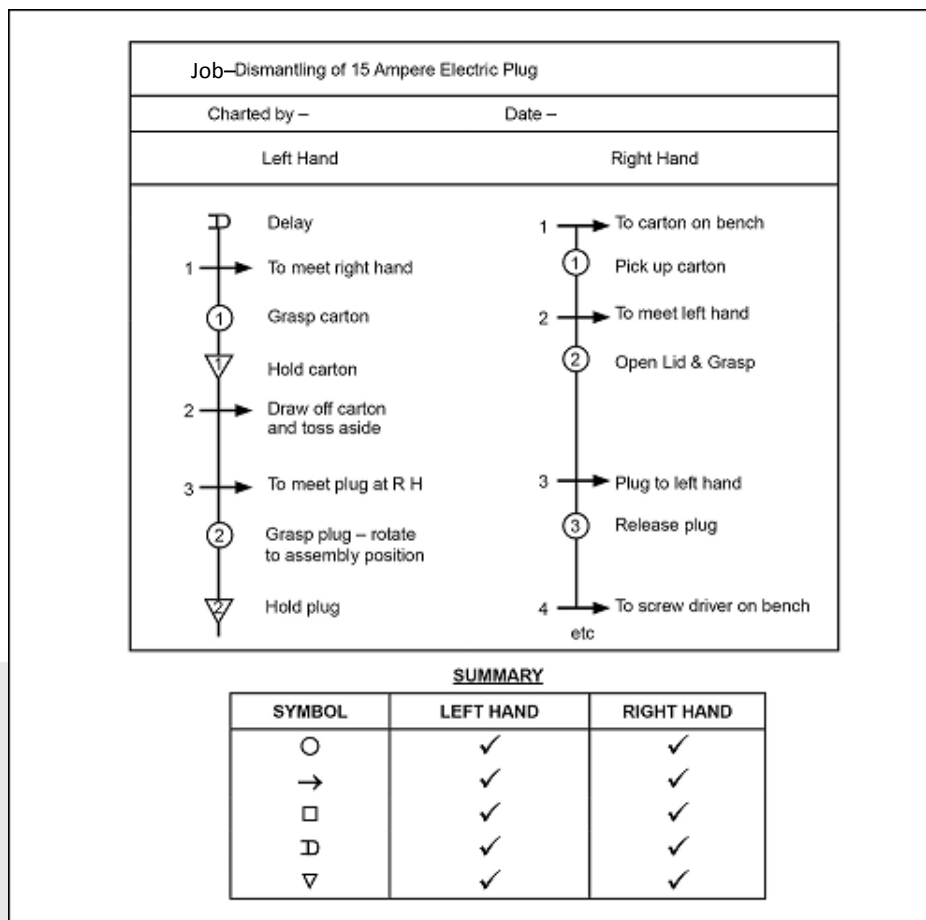


Fig. IV: Left Hand Right Hand Process Chart

Yet another type of diagram to depict flow is the **string diagram**, Figure VII (shown ahead). It is a scale plan or model on which a thread or a string is used to trace and measure the path of workers, materials or equipment during a specified sequence of events. String diagrams can deal with complex movements and range over many classes of work. They have been used to cover movement throughout a whole building, and by contrast to illustrate the movement of an operator's hands at a work bench.

Though not very popularly used in our country because of high costs, we could also use SIMO (Simultaneous Motion) charts or you could also resort to a **cycle graph**. This technique was developed by Gilbreth to help overcome the difficulties of accurately plotting movements that are too fast for the eye to follow. A **cycle graph** is a record of the path of movement, usually traced by a continuous source of light on a photograph, preferably stereoscopic. One of the defects is that it does not indicate speed or direction of movement. Hence this resulted in development of **chronocycle graph**. Here the light source is suitably interrupted so that the path appears as a series of pear-shaped spots, the pointer indicating the direction of movement and the spacing between the spots indicating the speed of movement.

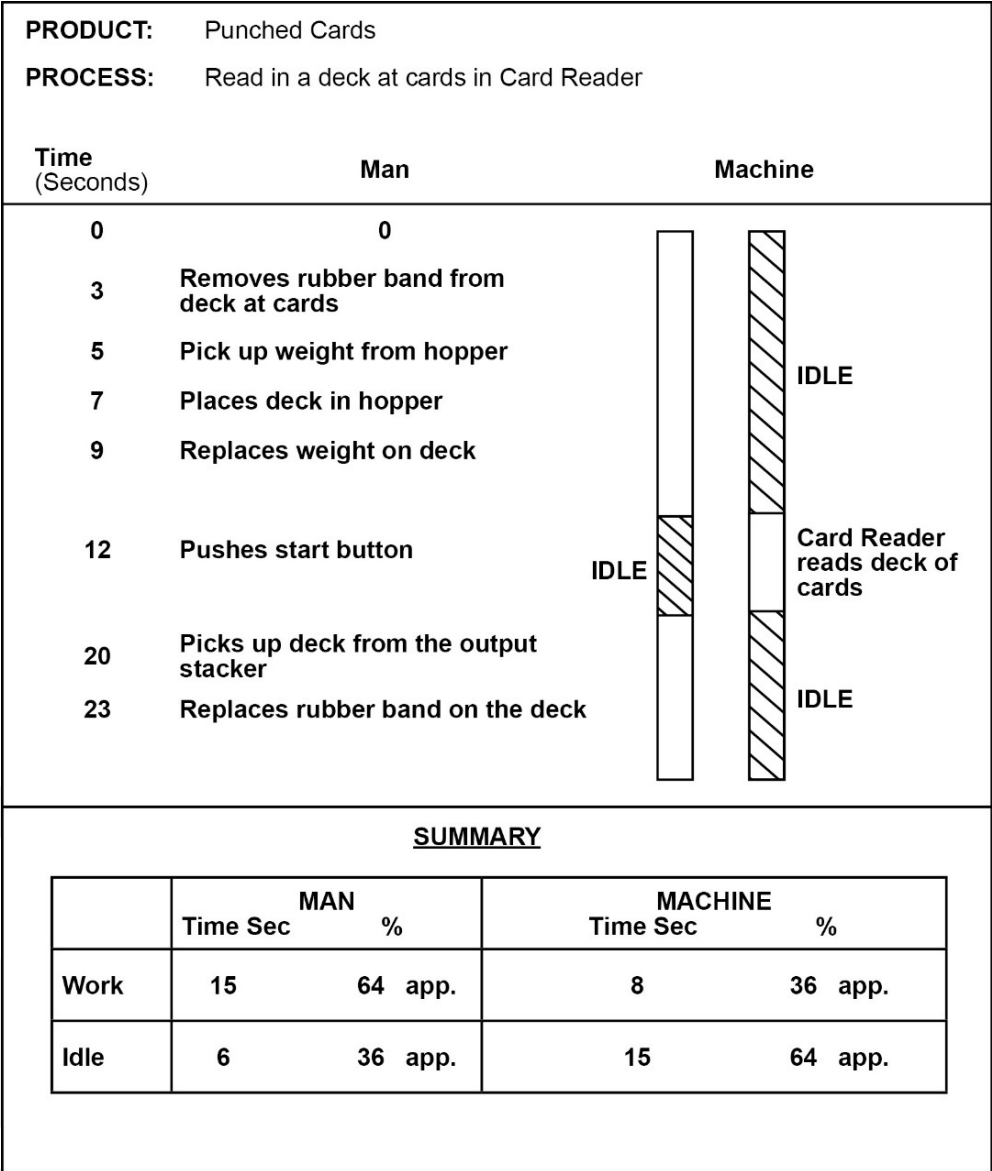


Fig. V: Man-Machine Activity Chart (Multiple Activity Chart)

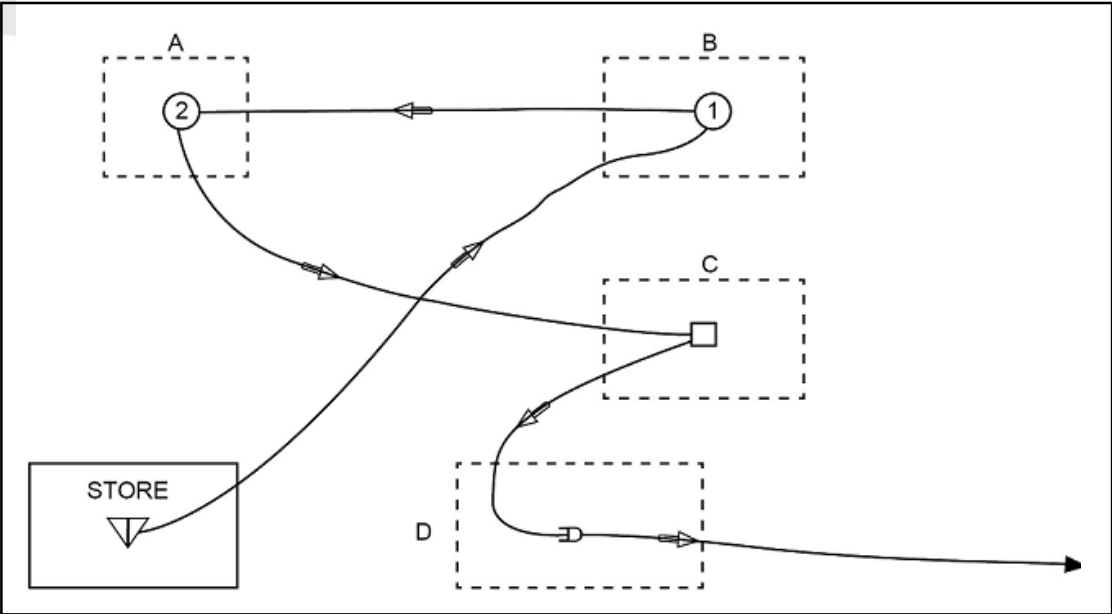


Fig. VI: Flow Diagram

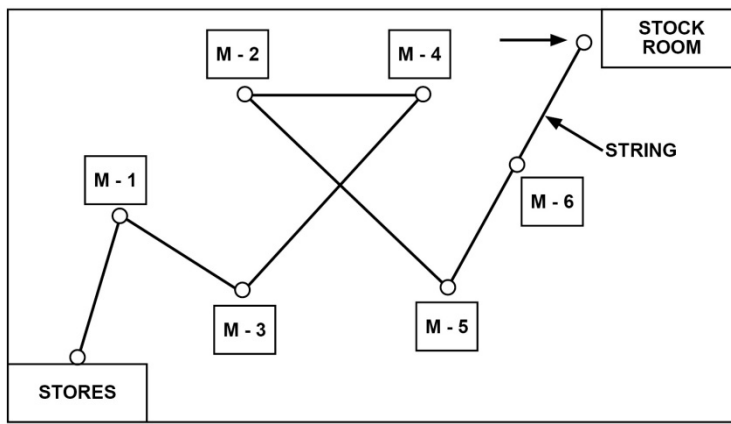


Fig. VII: String Diagram

Examination

After 'record' comes 'examine'. In method study, problems are typically solved by examining critically and systematically the facts that have been collected and recorded in some form of process charts. Close examination of the events/activities in any working situation usually reveals a number of key stages in the progress of the job. Preceding the key activity would be a chain of 'Put away activities'. Obviously, therefore, attention ought to, first of all, be concentrated on these key activities which Gilbreth termed as 'Do-operations'. Critical examination may yield the futility of the key activity and, in one stroke, many of the preceding and succeeding activities might just as well be 'washed off'. Key activities could preferably be coloured or shown hatched in the process charts after the 'record' stage.

Perhaps the best known standard approach to 'examine' is the critical examination technique proposed and used by ICI (Imperial Chemical Industries) Ltd. in UK. It is usually a group activity where several persons assist each other in the questioning process in an impartial and objective manner. There are essentially two types of questions-primary questions and secondary questions.

Primary-the first stage of the questioning technique which queries the fundamental need for the performance, place, sequence, person and means of every activity recorded, and seeks a reason for each reply.

Secondary-the second stage of the questioning technique whereby the answers to the primary questions are subjected to further scrutiny to determine whether possible alternatives of place, sequence, persons and/or means are practicable and preferable as a means of improvement over the existing method.

Let us take a common problem for critical examination that is faced daily at home viz., the job of **washing up after a meal**. If this be the key activity or 'do' operation, there are the set of 'make ready' activities like removing used plates from the dining table, carrying them off to the wash basin in the kitchen, filling bowl with lukewarm water etc. The 'put away' activities would be drying dishes after washing, moving dishes after washing to draining board,

inspection of the dishes after washing etc. It should be fairly obvious to you that the most important key activity of the whole process is the 'do operation' of washing the dishes. Everything else in washing-up is subordinate to this, and so our attention is focused first on this activity.

Key Activity/Do operation: Wash dishes after meal.

Purpose-Primary

What is the purpose? What is achieved?

Food remaining after the meal is removed from the surface of the dishes. Is this necessary? If so, why?

The dishes are used again for meals. Any 'jootha' food left adhering to the plates goes stale. This is unhealthy and also unethical (as per our value system).

Purpose-Secondary

What else could be done? Can the operation be eliminated? Or modified? How? Use disposable plates or 'pattals'. Use the existing plates with disposable napkins. Don't use plates.

The previous set of alternatives might lead you back to answer the question-'Was the meal itself necessary? Could an apple or some fruits serve the purpose? Could the meal have been eaten in a restaurant? (Surely this might be a costly proposition if it is to be done daily).

Perhaps the 'buffet' system could have been implemented. This could have cut down drastically on the number of plates used.

In order to bring the **do** operation into greater focus, the **place, sequence, person, and means** aspects are considered next.

Place-Primary

Where is it done? In a bowl in the kitchen sink.

Why there? Hot and cold water is available from nearby taps. Dirty water is easily got rid of down the drain.

Place-Secondary

Where else could it be done? In the sink itself, without the bowl or on the kitchen table in the bowl.

Sequence-Primary

When is it done? Immediately after the meal has finished.

Why then? Customary. Food particles are still easily washed off at this stage.

Sequence-Secondary

When else could it be done? Can it be delayed, or brought forward? Can the sequence be changed?

After each course or just before the next meal or once per day.

Person-Primary

Who does it? Normally the housewife.

Why that person? Possibly because of the Indian value system.

Person-Secondary

Who else could do it? Can the grade of labour be changed?

The husband, the children, relatives or perhaps a domestic servant.

The questions-What? Why? When? Where? and Who? — have been asked and answered. As regards how, perhaps there is no need to ask in case dishes are not to be washed at all. However, in case dishes are to be washed, then greater details of the washing process, selection and procurement of equipment would have to be recommended on the basis of value analysis studies. All the above material should then lead to the next stage in the investigation, viz. development of the new method.

Development

After developing the alternatives and their consequences, a final selection based on an appropriate criteria is to be done in order to develop the new method. This approved method can be drawn up in a process chart form. This is then compared with the existing method. A summary of the number of operations, delays, inspections, storages and the total distances should be made. You will invariably find that there would be considerable reductions in the 'non-productive' areas. The proposals for improvement can now be submitted for approval.

Installation

And so now you have reached the final stages of method study. Installation can be divided into five phases:

- 1) Gain acceptance of change by departmental supervision.
- 2) Gain approval of change by works and general management.
- 3) Gain acceptance of change by workers involved and their representatives.
- 4) Retain the workers to operate new methods.
- 5) Continual monitoring of whether or not the new method is being used.

The last phase is in fact a function of the maintenance stage. Casual changes in method may arise for a variety of reasons. They need to be monitored and reviewed by the work study analyst in an impartial manner.

In the sections that will follow, we focus our attention to the other component of work study namely work measurement.

10.4 WORK MEASUREMENT

Work measurement is concerned with the determination of the amount of time required to perform a unit of work. It provides management with a basis for comparison of alternative methods, and also a basis for initial manning. Moreover, it makes available the necessary data for effective planning and scheduling and provides a basis for wage and salary administration especially for devising sound incentive schemes.

Work Measurement Procedure

The basic steps to be followed sequentially for work measurement are:

- 1) **Select** the work to be studied, after having made a preliminary survey.
- 2) **Record** all the relevant data pertaining to the circumstances in which the work is being done, the methods and the elements of activity in them.
- 3) **Measure** each element in terms of **time over a sufficient number of cycles** of activity to ensure that a representative picture has been obtained.
- 4) **Examine** the recorded data and time elements **critically** to ensure that unproductive or random elements are separated from productive elements; also examine the recorded times of each element and determine a representative time for each.
- 5) **Compile** a time for the operation which will provide a realistic standard of performance and will include time allowances to cover suitable rest, personal needs and contingencies etc.
- 6) **Define** precisely the series of activities and method of operation for which the time has been allowed and issue the standard time for the activities and methods specified.

The above steps of work measurement are essentially a three-stage procedure of **analysis, measurement and synthesis**. The analysis stage occurs when the work to be measured is broken down into its constituent parts. Measurement takes place when the available information is gathered together into a suitable form for use. It is important to appreciate that the three stages are closely connected with each other.

Techniques of Work Measurement

The principal techniques used to measure work are:

- a) Time study
- b) Work sampling
- c) Pre-determined motion-time system (PMTS)
- d) Analytical estimating

- e) Synthesis from standard data
- f) MOST.

The first two techniques would be discussed in detail in this unit, whereas the remaining ones would be explained only very briefly.

Some Common Terms used In Work Measurement

Observed Time— It is the time directly recording by stop watch by the work study man observing the activity of the operator.

Basic Time or Normal time – It is the calculated time of the activity of the operator taking into account his rate of performance. It is equal to observed

time $\times \frac{\text{Observing rating}}{\text{Standard rating (100\%)}}$. For example, if the observed time of the operator is 5 minutes (say) and he is working at a faster rate of 120% rating (according to the concept of work study man), then the Basic

Time = $5 \times \frac{120}{100} = 6$ minutes. On the other hand, suppose the operator is doing work at a slower rate of 90% (according to the concept of work study man) then the Basic time = $5 \times \frac{90}{100} = 4.5$ minutes.

Rating Factor (Performance Rating)— It is a comparison of the actual performance with some standard notion or normal performance. Normal performance is the working rate of the average worker working under capable supervision but without the stimulus of an incentive wage plan. Thus a rating factor of 1.25 means the operator is working at a faster rate of 125% compared to 100% normal performance according to the concept of the work study analyst. Similarly a rating factor of 0.90 means an efficiency of 90% compared to the 100% concept of the analyst. As human judgement is involved, the rating is recorded in steps of 5% i.e., 80, 85, 90, 95, 100, 105, 110, 120 etc.

Allowances — It is the time value added to the basic time of the operator to provide the worker with an opportunity to recover from the physiological and psychological effects of carrying out specified work under specified conditions. Ordinarily two types of allowances are used - relaxation allowance and contingency allowance (explained later).

Standard Time — It is the allowed time which is determined to be necessary for a quality worker working at a pace which is ordinarily used under capable supervision and experiencing fatigue to do a defined amount of work of specified quality when following the prescribed method.

Time Study

Time study is a technique for determining as accurately as possible from a limited number of observations, the time necessary to carry out a given activity at a defined level of performance.

Objective. The objective of time study is to determine by direct observation, by stop watch, the quantity of human work in a specified task and hence to derive the proper time for the task. Here we make Macro-motion study of elements of job having duration time of 3-4 secs.

Time study procedure. Basic time study equipment or tools consist of a stop watch, a study board, pencils, a pocket calculator, and measuring instruments for distance and speed (such as s ruler tape measure, micrometer and technometer/revolution counter) See Fig VIII

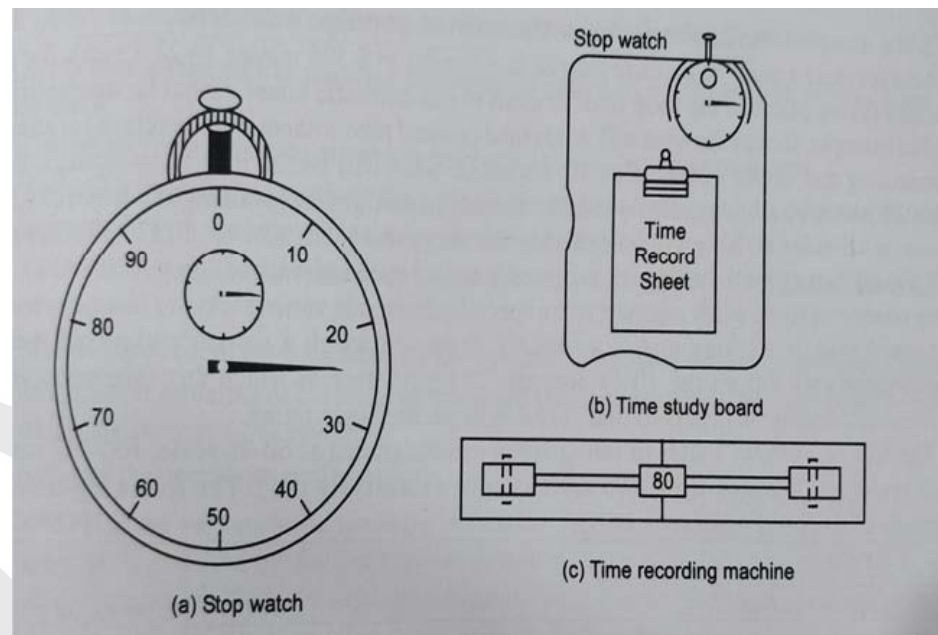


Fig. VIII: Time Study Equipment

The basic steps in time study procedure are as follows:

- 1) **SELECT** the job to be studied (short cycle or long cycle, repetitive or non-repetitive). A job might be selected for a variety of reasons. It could be because of:
 - a) a new job,
 - b) a change in method for which a new standard time is needed,
 - c) a complaint received from workers or their representatives about time allowed for an operation,
 - d) a bottleneck operation,
 - e) a change in management policy such as the introduction or withdrawal of an incentive scheme.
- 2) **RECORD** all the information about the job, the operator and the surrounding conditions which are likely to affect carrying out of the work. Plan the programme by which all the constituents can be measured economically and accurately, record a complete description of the method and break down the operation into elements which could be conveniently observed, measured, analysed and synthesised.

- 3) **MEASURE** with a stop watch the time for each element repeated for sufficient number of cycles, so as to provide reliable data covering all expected conditions. **Also while observing, do not forget to assess the effective speed of the working of the operator relating to a predetermined ‘normal’ speed. This process is called “Performance Rating” and if it is not reliable enough it could be a bone of contention between the various relevant parties.** Now we shall define the term **“Performance Rating”**.

By definition rating is a comparison of actual performance with some standard notion or normal performance. Normal performance (or pace) is the working rate of the average worker working under capable supervision but without the stimulus of an incentive wage plan. This pace can easily be maintained day after day without undue physical or mental fatigue and is characterised by the fairly steady exertion of reasonable effort.

Some accepted standard or norms are that average person walks at a speed of about 4 miles per hour, or deal a pack of cards (52 cards in 4 hands) in 0.375 minute (=22.5 secs). But all the activities taking place on the shop floor or even in our domestic house cannot be standardized like this. For example, if one asks what will be the time (normal time without undue exertion) of assembling a connecting rod in the piston of an IC engine or what will be the time in sweeping a floor of 15 ft × 12ft size by a broomstick, we shall be stumped outright. But walking at a speed of 4.5 miles an hour or 3.5 miles an hour will immediately bring a spontaneous answer of 112.5 efficient walk or 87.5% efficiency walk (taking the accepted standard speed of walk of 4 m.p.h as 100%). Which is why observers (time study engineers) are specially trained in various ways to be able to recognize the normal rate of working and to assess the degree to which a worker's observed speed and effectiveness varies from the 100% concept. The procedure in which this assessment is noted simultaneously with the observed time, is taken as **performance rating**.

The following three scales of rating are in use **designated** as 60-80 scale, 100-133 scale and 0-100 scale out of which the 0-100 scale is most extensively used. The following table shows examples of different scales.

Table 1

Scales			Description	Equivalent walking speed (m.p.h)
60-80	100-133	0-100		
0	0	0	No activity	0
40	67	50	Very slow, clumsy, operator appears half sleep with no interest in the job.	2

60	100	75	Normal, steady, unhurried performance.	3
80	133	100	Brisk, businesslike performance as of an average qualified worker on piece rate	4
100	167	125	Very fast, operator exhibits a high degree of assurance, dexterity and coordination of movement well above that of an average trained worker.	5

In the scale 0-100 the figure 100 represents standard performance. If the study man decides that the operation he is observing is being performed with less effective speed than his concept of standards, he will use a factor of less than 100. If on the other hand he decides that the effective rate of working is faster, he gives it a factor greater than 100.

Thus basic time (or normal time) = $\text{Observed time} \times \frac{\text{Rating}}{\text{Standard rating (100)}}$

For example , if observed time is 0.16 minute and the worker is working at a faster rate of 125% rating (according to the concept of the study man) then

the basic time= $0.16 \times \frac{125}{100} = 0.20 \text{ minute}$

Performance rating or rating factor is generally taken to be:

Table 2

Extremely good	150%	Poor	90%
Very good	130%	Very poor	80%
Good	110%	Extremely poor	70%
Normal	100%		

Need for evaluating performance : The basic purpose of rating is to bring the operatives having different capability of working to one standard (normal level) and then to compute the standard time.

- 4) **COMPILE** the various basic times for the entire element activities. After establishing the basic time per cycle required by the qualified worker to perform each element at standard rate of working, it is necessary to find out what percentage of time should be added to each element to allow for fatigue, personal needs or other contingencies. **Relaxation Allowance (RA)** is added to the basic time which intends to provide the worker with the opportunity to recover from the physiological and psychological effects of carrying out specified work under specified conditions. Following are the principal factors for which RA percent is provided.

- i) Motions
- ii) Personal needs including basic fatigue

- iii) Energy output
- iv) Thermal conditions
- v) Atmospheric conditions
- vi) Visual fatigue
- vii) Other influences of environment.

Added to the above yet another allowance (in %) known as the **Contingency Allowance (CA)** accounting for the following contingencies.

- i) Shapening of tools
- ii) Obtaining special materials
- iii) Obtaining a special purpose equipment from a central tool room
- iv) Consulation with the supervisor
- v) Consulting a manual or work order for specifications.

And finally any other allowance, which the company thinks fit under its policy decision is added to compute the standard times.

Thus standard time = Basic time + RA + CA + any other allowance (Fig.IX)

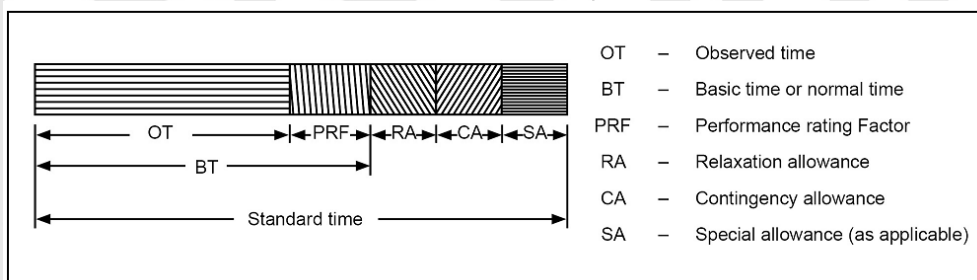


Fig. ix

Standard Time may be defined to be the allowed time which is determined to be necessary for a qualified worker, working at a pace which is ordinarily used under capable supervision and experiencing fatigue to do a defined amount of work of specified quality when following the prescribed method.

- 5) **DEFINE** all the activities covered now and issue the allowed time for a particular job/ operation. Obviously, this allowed time should have the approval of the management and the support of the employees and their representatives so that no conflict occurs when the plan is actually put into practice.

It is important, however, for the time study man to have taken sufficient number of readings. This can be determined by using the following formula which is based on a normal distribution for 95% level of confidence and a precision need of predicting the final results within $\pm 5\%$ accuracy.

$$N_{\text{expected}} = \left[\frac{40\sqrt{NEX^2 - (\Sigma X)^2}}{\Sigma X} \right]^2 = \text{How many cycles to be timed.}$$

where N denotes observations already taken and X represents the value of each observation

$N_{expected}$ = Sufficient no. of readings.

Standard Data

It is a catalogue of basic time or normal time values for different elements of job or for minute movements involved in different jobs. The catalogue is prepared by compiling the timings of a number of standard elements.

Example 10.1

The time taken for an element in a time study for 30 observations revealed the following information:

x(in seconds)	0.05	0.06	0.07	0.08
y(frequency).	14	14	1	1

Have sufficient observation been taken for precision of $\pm 5\%$ and 95% confidence level?

Solution

f	x	fx	fx^2
14	0.05	0.70	0.0350
14	0.06	0.84	0.0504
1	0.07	0.07	0.0049
1	0.08	0.08	0.0064
Total = 30	—	= 1.69	= 0.967
$\sum f = N$	—	$= \sum fx = \sum X$	$= \sum fx^2 = \sum X^2$

$$N = \left\{ \frac{40 \sqrt{n \sum X^2 - (\sum X)^2}}{\sum x} \right\}^2 = \left\{ \frac{40 \sqrt{30 \times 0.967 - (1.69)^2}}{1.69} \right\}^2$$

=26 observations < 30 $\therefore$ Sufficient observations have already been taken.

Example 10.2 Consider the key punching operation for invoice which consists of the following elements in sequence.

- 1) Pick up an invoice, place it next to the CRT (Cathode Ray Tube) Terminal
- 2) Punch in the data on the terminal keyboard.
- 3) Place the invoice aside.

A stop watch time study for 10 cycles was conducted. Stop watch readings (in 1/100 minute) were taken at the start of each element. These are shown in the R columns below illustrating the time study worksheet (Random Numbers are used in each cycle for each element). If the performance rating (PR) of 120%, 110% and 110% to the elements 1, 2 and 3 are assigned

respectively and the company has decided to give at best an allowance of 5% of the normal time taken by each element, determine the standard allowed time for the operation. (T = individual observed time for each element), R-Reading.

Cycle No. Element Description	1		2		3		4		5		6		7		8		9		10	
	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T
Element No. (1)	08	08	37	07	66	08	01*	09	33	08	66	10	97	10	27	08	60	09	91	08
Element No. (2)	22	14	51	14	84	18	16	15	47	14	80	14	12	15	43	16	76	16	05	14
Element No. (3)	30	08	88	07	93	08	25	09	86	09	87	07	19	07	81	08	83	07	13	08

* 01 means 101 and so on.

Explanation: 08+14 = 22, 22+08 = 30, 30+07 = 37, 37+14 = 51...and so on. See column 2,3,4,5.. etc.

Solution. Total of Element No. (1) times

$$= 08 + 07 + 08 + 09 + 08 + 10 + 10 + 08 + 09 + 08 = 85$$

$$\therefore \text{Average element time} = 85/10 = 8.5$$

$$\text{Total of element No. (2) times} = 14 + 14 + 18 + 15 + 14 + 14 + 15 + 16 + 16 + 14 = 150$$

$$\therefore \text{Average element time} = \frac{150}{10} = 15$$

$$\text{Total of Element No. (3) times} = 08 + 07 + 08 + 09 + 09 + 07 + 07 + 08 + 07 + 08 = 78$$

$$\therefore \text{Average element time} = \frac{78}{10} = 7.8$$

Calculation Table

Element No.	Average Element Time	Rating	Normal Time	5% Allowance	Std. time
(1)	8.5	120% or 1.2	$8.5 \times 1.2 = 10.2$	$10.2 \times \frac{5}{100} = 0.5$	10.2 + 0.5 = 10.7
(2)	15.0	110% or 1.1	$15 \times 1.1 = 16.5$	$16.5 \times \frac{5}{100} = 0.8$	16.5 + 0.8 = 17.3
(3)	7.8	110% or 1.1	$7.8 \times 1.1 = 8.6$	$8.6 \times \frac{5}{100} = 0.4$	8.6 + 0.4 = 9.0
					Total = 37.0

i.e.. Standard time = 0.37 min. **Ans.**

(Note: Can you tell how many observations are required to have been taken ?)

Example 10.3 Determine the standard time for the following job. Add 20% for allowance. The times shown are continuous stop watch readings

in hundredths of a minute. Performance rating factor for elements 1, 2 and 3 are 120%, 110% and 95% respectively.

Element	Cycle					
	I	2	3	4	5	6
(1) Put glycerine on thumb, fore-finger and middle finger of both the hands, (for counting sheets)	05	—	63	—	117	—
(2) Take out 4 sheets each with each hand from pile of sheets placed on either side of the operator.	20	46	77	101	150*	176
(3) Staple 8 sheets together and put them in a tray	30	57	87	112	161	186

*the operator dropped 4 sheets on the floor and then picked up and stapled them with another 4 sheets.

Decide whether the starred (*) time has to be deleted from the calculation of the standard time or not? Justify your answer.

Solution.

Element	Cycle time					
	1	2	3	4	5	6
(1)	05	—	06	—	05	—
(2)	15 (=20-5)	16	14	14	33*	15
(3)	10 (=30-20)	11	10	11	II	10

* this reading is thrown out.

Calculation Table

Element No.	Total time for the element	Cycle	Average time	Rating	Normal time	Allowance (20% of NT)	Std. time
1	16	6	$16/6 = 2.67$	1.20	3.204	0.641	3.845
2	74	5	$74/5 = 14.80$	1.10	16.280	3.256	19.536
3	63	6	$63/6 = 10.50$	0.95	9.975	1.995	11.970

Total = 35.351

i.e. Standard time = 0.354 minutes

Note: The operator dropped four sheets on the floor due to his own negligence and so the time period of picking up sheets from the floor cannot be legally taken into account in the calculation table. We, therefore discard the data starred.

Learning Curve – it is defined as the ability of a person under certain circumstances to increase one's efficiency or skill by a constant rate as

the cumulative production quantity increases geometrically (that is, increases by doubling).

One word of caution in trying to establish standards. It could happen that the operator selected for time study is performing the job for the first time. Sometimes it could also be the case when the operations being performed are complex in nature. In such cases, it is quite possible that initially the operator takes longer time to accomplish these jobs as compared to the subsequent cycles when he would have acquired the necessary skill and feel in learning the job. Usually, this learning curve is hyperbolic in nature, as shown in Figure X.

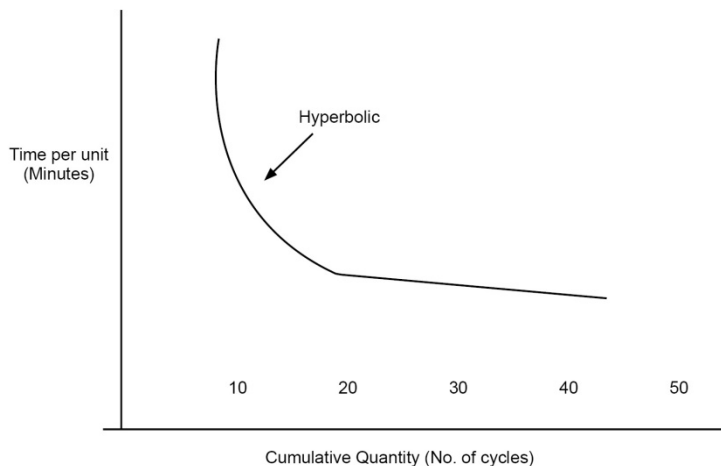


Fig. x: Learning Curve

Some of the advantages of a learning curve are:

- 1) It allows us to predict the cost of a future product or an operation.
- 2) It determines the point where we can start to apply work measurement for establishing the standard time for an operation.
- 3) Sometimes it could also provide a basis for transfer and promotion of employees.

The general approach to determining the rate of learning is to identify the relative importance of each factor contributing to learning. Can the causes and influences be measured and predicted? Though the 'learning curve' concept is an important one, yet it seems that it has not been given due importance. We feel it would be unfair if 'learning phase' is not accounted for while determining standard..

Work Sampling (Activity Sampling)

It is based on the statistical method first devised by L.H.C. Tippett in 1934 who used this method for determining the causes of loom stoppages while working for the British Cotton Industry Research Institute. **Work sampling is a fact finding tool and a measurement technique for quantitative analysis in terms of time, of the activity of operators, machines or of any observable state or condition of operation.**

This tool is particularly useful when information is urgently needed about men or machines, especially in the analysis of non-repetitive or irregularly occurring activity where no complete method and frequency description are available.

Work sampling can be used to study almost any type of work; repetitive or non-repetitive, factory or office, executive or supervisory, clerical or engineering, handlers, salesmen, nurses and what you have.

Work sampling is a method of randomly observing work, noting state and condition of the object being studied. From the proportion of observations in each category, inferences are drawn concerning the total work activity under study.

Uses of Work Sampling. Work sampling provides a way to :

- 1) obtain information about either certain long cycle work or non-repetitive type of jobs for which it would be clearly impractical to use continuous observation methods.
- 2) indicate if certain activities should be studied in details.
- 3) help design the work load distribution in formulating a new work system
- 4) study any operation for possible methods improvement.
- 5) help establish job content as an aid to job evaluation and employment purposes.
- 6) aid supervisors to organise their time.
- 7) aid appraisal of shop effectiveness, efficiency, safety performance etc.
- 8) provide feedback information about compliance to stated management policies.
- 9) assist in establishing standards of performance.
- 10) establish control on labour, material or machine utilization.

The object of the observations may be personnel, equipment or facilities which can be categorised as follows:

Typical categories applied to people are:

- a) working
- b) being idle
- c) being out of area
- d) walking
- e) handling material
- f) inspecting
- g) changing tools
- h) clearing up
- i) handling clerical tasks

j) talking.

Typical categories applied to machines/equipments are :

- a) at work
- b) idle - no operator
- c) idle - no stock
- d) idle - being serviced
- e) idle - interference.

Fundamental Concept. Based upon the law of probability, it can be said that a sample taken at random from a large group tends to have the same pattern of distribution as the large parent group and if the sample is large enough, the characteristics of the sample will differ very little from the characteristics of the parent group or population. Sampling is the analysis of the characteristics of a population based on the analysis of a small group collected at random from it.

The sampling process should be completely unbiased and each part comprising the population must have an equal chance of being drawn. This can be ensured with the help of random sampling. It is necessary to decide before hand what level of confidence is desired in the final work sampling results. The most commonly used confidence level is 95% which means that one is confident that 95% of the time the random observations will represent the facts and that 5% of the time they will not.

For 95% confidence level, a relationship exists between number of observations (N), the extent of the phenomenon being observed-expressed as decimal (p) and the accuracy of the sample results (s). This is given below : (If p = 25% and s = ±4% it means the value of N calculated out would be valid for the range of p as 25% ± 4% of 25 i.e., 24% to 26% at the said confidence level).

For 95% confidence level :

$$sp = 2 \sqrt{\frac{p(1-p)}{N}}$$

For 70% confidence level, $sp = \sqrt{\frac{p(1-p)}{N}}$

For 99% confidence level, $sp = 3 \sqrt{\frac{p(1-p)}{N}}$

Illustration

Given: p= 34%, s = ± 4%. confidence level is 95%, then $N = \frac{4p(1-p)}{s^2 p^2} = 4853$ observations.

Advantages of Work Sampling

- 1) It is more economical and less time consuming than time study.
- 2) It is easy and convenient to use as no stopwatch or other timing devices are needed.
- 3) It can be used to measure several activities (e.g., retail stores, offices, warehouses etc.) that cannot be measured by time study.
- 4) No trained analyst is required to make observations.
- 5) Work sampling measures the utilization of workers and equipment directly.
- 6) Measurement can be made with a pre-determined degree of reliability.
- 7) It faces less resistance from the workers.

Limitations of Work Sampling

- 1) Unlike time study methods, it provides little help in improving work technique.
- 2) It is not economical for studying work at a single location or highly standardized work.
- 3) If observers do not adhere to the fundamental principles of sampling, results become biased.
- 4) Management and workers may not understand statistical work sampling.

Accuracy of Activity Sampling Measurement

Limits of accuracy (s) refers to the permissible variations of the results of the study from the true mean of the situation. Though the figure of limits of accuracy varies depending upon the objective of the study it is common practice to pick up the figure between the range from 2% to 5%.

When one determines the degree of accuracy desired in the activity sampling, he is in fact determining number of observations required. The number of such observations in turn effect the time and cost of making the study. The purpose of the activity sampling study thus should suggest the degree of accuracy of results required.

In designing the work sampling study analyst must size up the entire situation. A proper balance between the accuracy desired and the economics of the study must be struck. Fortunately in a work sampling study the analyst can determine in advance the number of observations needed for a given degree of statistical accuracy using the formula mentioned above.

The steps for an activity sampling study may be described as follows:

- 1) Define the problem.
- 2) Get the approval of the supervisor of the department concerned in which the study is to be made to ensure the co-operation of the operators to be studied
- 3) Determine the desired accuracy of the final results and the confidence level
- 4) Make a preliminary estimate of the percentage occurrence of the activity or delay to be measured.
- 5) Design the study.
 - (i) Determine the number of observations to be made
 - (ii) Determine the number of observers needed.
 - (iii) Select and instruct these people
 - (iv) Determine the number of shifts needed for the study
 - (v) Make detailed working plan for taking the observations.
 - (vi) Design the observation form
- 6) Make the observations according to the plan
- 7) Analyse and summarize the data thus obtained
- 8) Check the accuracy or precision of the data at the end of the study.
- 9) Prepare report with conclusions

An Activity Sampling Observation Sheet is shown below for determining the percentage idle time of the working force in a machine shop.

Table. 3: Activity sampling observations sheet

Date	Observer							Study No.			
Tour No. Operator	1	2	3	4	5	6	7	8	9	10	11
1	W	W	W	A	—	—	—	—	—	—	—
2	W	I	W	W	—	—	—	—	—	—	—
3	W	W	RA	W	—	—	—	—	—	—	—
4	W	W	W	W	—	—	—	—	—	—	—
5	W	W	W	W	—	—	—	—	—	—	—
6	W	W	W	RA	—	—	—	—	—	—	—
7	W	I	W	W	—	—	—	—	—	—	—
8	W	I	W	W	—	—	—	—	—	—	—
9	W	W	W	I	—	—	—	—	—	—	—
10	W	W	RA	W	—	—	—	—	—	—	—

Code: W= Operative Working, I= Operative idle, RA= Operative taking authorised rest, A= Operative absent from work place.

Let us now discuss briefly some of the remaining techniques of work measurement.

Predetermined Motion Time System (PMTS)

BS 3138 : 1969 defines PMTS as a work measurement technique whereby time established for basic human motions (classified according to the nature of the motion and the conditions under which it is done) are used to build up the time for a job at a defined level of performance.

Every element of work is composed of some combination of basic human motions. Apart from mental activity, all work can be broken down into elements that are usually a fundamental movement of the body or body members. After this analysis stage, the basic motions that have been isolated have a time allotted to them on the basis of predetermined motion times. This is the measurement (or rather pre-measured) stage. The synthesis stage involves combining the basic motions in specific combinations and frequencies to form basic elements which would go to complete the total work operation. This method is particularly suited to situations where direct observations may not be possible or it may be some entirely new method of working which, however, is composed of work of basic elements which are standard with a new combination or mix. It is suited to both repetitive as well as non-repetitive work.

Analytical Estimating – Defined as a work measurement technique being a development of estimating whereby the time required to carry out elements of a job at a defined level of performance is estimated partly from knowledge and practical experience of the elements concerned and partly from synthetic data.

After the job has been broken down into its constituent elements in certain types of non-repetitive work, we find that analytical estimating serves as best for measuring work. In the analysis stage we find that usually these basic elements are much larger as compared to the elements in PMTS or time study. For the measuring stage, the time, which will be occupied by the element at a specific speed of working, is estimated. Many values may be obtained from the records of previous studies. The synthesis of all such records or data can be clubbed together for meaningful purpose.

Synthesis from Standard Data

Synthesis is a work measurement technique to build up normal time for a new job at a defined level of performance by adding element times collected from previously held time studies on similar jobs having small elements as possessed by the new job.

Now here we find yet another technique of work measurement to obtain synthetic times (or synthesised time standards) that are synthesised from

element times previously obtained from direct time studies. The analysis and measurement stages are thus conducted prior to the actual study. The technique primarily focuses on the synthesis stage. Most organisations that have had work studies conducted for some time usually build up synthetic tables covering the common elements in their own type of work. You could also refer to some standard tables, but be cautious in adapting it to your own organisations by duly keeping the framework in mind for which the standards might be applicable.

MOST Measurement System

The word MOST stands for Maynard Operation Sequence Technique. It is yet another work measurement technique. It was conceptualised around 1967 but was formalised only in 1975. The basic assumption here is that for an overwhelming majority of work, there is a common denominator from which work can be studied: the displacement of objects. In fact, all basic units of work are organised for the purpose of accomplishing some useful result by simply moving objects. **MOST is a system to measure work by concentrating on the movement of objects.** Consequently, MOST technique is composed of the following basic sequence models:

The General Move Sequence (for the spatial movement of an object freely through the air)

The Controlled Move Sequence (for the movement of an object when it remains in contact with a surface or is attached to another object during the movement)

The Tool Use Sequence (for the use of common hand tools).

In contrast to Methods Time Measurement, PMTS etc., the primary work units are no longer basic motions, but fundamental activities (collections of basic motions) dealing with moving objects.

At this stage we would like to stop our discussion of MOST and refer you to Zandine's book on MOST in case you are interested in further details on the topic.

10.5 WORKS STUDY APPLICATIONS

Work study techniques can be applied in a large number of situations. They are not necessarily confined to manufacturing at the shop floor level. Work study could be applied in office situations in which case the technique is more popularly known as O&M (Organisation & Methods). Work study could be applied in the Building Industry. In fact, Frank Gilbreth developed his ideas on time and motion study in a construction situation. Quite often, repetitive work is to be found on one site, e.g. laying precast concrete floor units, etc. Work study, particularly method study has, in such cases, been found to be very beneficial.

Again, we could utilise work study in the context of agriculture, which remains largely non-mechanised in our country. Savings in time and effort of farmers can be used to increase their effectiveness and efficiency. Identification and elimination of fatiguing, and costly or unproductive activities could be undertaken.

Work study could be used in a hospital setting also. Work study groups can achieve great success in the nursing patterns and staffing, ward design and hospital layout improvement in services such as catering, laundry work, domestic cleaning, typing, secretarial work and documentation etc.

In some countries abroad, work study has been used in national and local government services for maintenance of parks, playing fields, housing schemes, street cleaning, rubbish collection and disposal and post office sorting etc. It can also be used in defence services both for repair and logistic functions etc. Work study can also be used in hotel management for housekeeping, linen service, kitchen work, reception, preparation, cooking and serving of foods etc.

Work study personnel could also prove to be beneficial if they are included in design teams which require an inter-disciplinary approach for greater effectiveness.

Accordingly, work study people along with value analysts would certainly increase design worthiness.

10.6 INTRODUCTION TO JOB DESIGN

Job design is the consciously planned structuring of work effort performed by an individual or a team of persons. Good job designs must answer the job-related questions such as what work is to be performed, who is to perform the work, where the work is to be done, when the work is to be done, why the job is necessary and how should the work be accomplished. Job designers usually attempt to minimise the amount of physical human effort. Years ago, employers looked for workers with the physical capabilities to suit a given task. Today jobs are designed to suit an average worker and capability distinctions are more likely to be on the basis of education and experience.

For organisational purposes, we divide job design into two basic elements, a human element and a work element. Physiological, social and psychological considerations are important human factors relating to job design. The work element has been considered in detail in the previous unit. We shall, however, include some relevant points that we had deliberately left out while discussing work design. There is increasing evidence that poorly designed jobs are a pervasive societal problem affecting the mental and physical health of the worker both on and off the job. **The objective of job design is therefore to develop work assignments that meet the requirements of the organisation and the technology, and at the same time also satisfy the personal and individual requirements of the job holder.** The smallest work activities involve various elementary movements called **therbligs** (Gilbreth spelt

backwards), e.g. reach, grasp, position, release, search, select, transport, empty, hold, release, load, inspect, assemble, disassemble, use, plan etc. Micro-motions are made of therbligs whereas an element is an aggregation of two or more micro-motions. Two or more elements taken together form a task whereas the set of tasks that must be performed constitute a job the operator is to perform. Job design is a complex function because of the variety of factors that coalesce to create the ultimate job structure.

Degree of Labour Specialisation

Specialisation of labour is the two-edged sword of job design. On the one hand it has made possible high speed and low cost production, and has therefore increased our standard of living. On the other hand, extreme specialisation could lead to adverse effects on the worker, like boredom etc.

Advantages of specialisation to management are the following:

(i) rapid training of the workforce (ii) ease in recruiting new workers (iii) high output due to simple and repetitive work (iv) low wages due to ease of substitutability of labour and (v) close control over work flow and work loads. As for labour, there is little responsibility for output, little mental effort is required and little or no education is required to obtain work.

There seem to be some disadvantages also. The management may face difficulty in controlling quality since no one person has responsibility for the entire product.

Moreover, there could be 'hidden costs of worker dissatisfaction arising from turnover, absenteeism, tardiness, grievances and intentional disruption of production process. Disadvantages to labour could be: (a) boredom stemming from repetitive nature of work (b) little gratification from the work itself because of small contribution to each item (c) little or no control over the work pace leading to frustration and fatigue (d) little opportunity to progress to a better job since significant learning is hardly possible on fractionated or partial work (e) little opportunity to show initiative through developing better methods or tools (f) local muscular fatigue due to use of the same muscles in performing the task and (g) little opportunity for communication with fellow workers due to layout of work area.

As can be seen from the above discussion, disadvantages of specialisation seem to outweigh the advantages. Because of this researchers have come up with alternative approaches to job design. We now hear of human engineering, ergonomics, work physiology, job enlargement, job enrichment, job rotation, flexiturn and socio-technical systems approach, etc.

Ergonomics/Human Engineering

Every industrial system consists of some or all of the following components: hardware (the physical aspects), software (non-physical aspects), the physical environment and the organisation. An objective of the designer is to arrange

these components to give a harmonious and efficient operation, An objective of ergonomics is to match, or provide the information to match, the various other parts of the system to the characteristics and abilities of the people involved in it. By utilising ergonomics, the designer's opportunities to create a system which reliably achieves its function are improved. **Ergonomics is somewhat synonymous with human factors with engineering which is a field of study concerned with the abilities and limitations of human beings in the design of tools, instruments and work places.** Let us first discuss Job Design by elaborating on the design, environmental and organisational factors. These can be subsequently complemented by behavioural dimensions and the need for adopting a socio-technical approach.

10.7 DESIGN FACTORS (Technological Factor)

Layout of Equipment and Seating

Ideally, equipment design should start with the operator. Often a piece of equipment is first designed and then the operator is added as a kind of afterthought who has to cope with unsatisfactory arrangements of display and control as best as he can. Quite often, it is assumed that because a machine has always been the way it is, there is no good reason to change it. The attitude is one of 'what was good for our grandfathers is good enough for us'. The effects of tradition acting in this way is the rule rather than an exception.

Thus many equipments, though inconvenient, undergo no change for ages owing to this attitude. In some machine, for example, controls may come in a comfortable position for the hand, but the work might be too far away from the eye and as a result the operator has to operate in a bent posture while working on, say, centre lathes.

Why not think of a tilted centre lathe so that the operator can see without stooping?

Vision of old type of crane cabs was bad. Redesigned crane cabs now provide unrestricted vision that place much less strain on the driver thereby increasing his efficiency.

For good design, the designer ought to start out with the operator by laying out the areas for vision, for controls, for sitting and, for leg room etc. by taking note of standard anthropometric data of men and women, as the case may be. Job design should consider whether the job is to be done standing or sitting or in both the ways. You would probably observe that people leave their work places after regular intervals in order to obtain a change of posture. It is not very surprising to note that workers find it necessary to stand up from time to time probably because the seats provided are too uncomfortable to be sat upon for more than a limited period.

It is the requirement of good seating that the person while sitting should be able to maintain a good posture which will not cause overstrain of any particular group of muscles. The use of a well designed and positioned back rest may relieve the back muscles of a good deal of postural strain. Moreover, the seat should not press unduly on the tissues of buttocks. The pressure will restrict the blood flow which may cause pressure on the nerve trunk which runs on the underside of the thigh and will cause discomfort which could also sometimes cause the need 'to go to sleep' and induce numbness. A well designed seat should therefore bear the weight of the body in a good posture on the hips and not on the thighs. The elements of good seating will depend on the length, width and shape of the seat; material of which the seat is made; the shape and height of the backrest and the height of the seat above the floor. When high chairs are used at work benches, there will have to be some type of footrest which should preferably be a flat surface rather than a bar which causes fatigue by forcing the operator to keep the foot in a fixed position. Sometimes it may be useful to provide some standing supports or 'rump rests'. In contrast to the work situations, seats which will be used for relaxation can be somewhat lower than office and factory chairs.

On the contrary, there are quite a few advantages in working at floor level. This is popular amongst workers of many categories such as cobblers, tailors, etc. Workers have greater freedom to move their legs and bodies. Sometimes consultants might provide operators with some sort of a stool or a bench out of human considerations. It is usually seen that such aids are not used subsequently for sitting purposes; rather the operators would place their tiffin boxes, small bags and shawls etc. on these stools.

However, when benches are laid out for assembly work or when controls are positioned, the general principles of motion economy as laid down by Gilbreth should be taken as a guideline. It is now being realised that reducing movements too much could cause local muscular fatigue which will not be present if the actions are spread over more muscles in the body. Accurate positioning of manipulative movements should be made near the body and controls which need fine adjustment should be placed close to and opposite the hand which will operate them. In case a worker is to operate a foot pedal, the return spring pressure on the pedal should be sufficient to support the weight of the foot or of the leg as the case may be; otherwise very tiring static work will have to be done to maintain either a foot or a leg in the 'off' position. In extreme cases, muscular damage can be caused by pedals with insufficient pressure operate for a long period of time.

In case of controls, information should preferably be given to the operators in a binary form of 'yes-no' type. Alternative lights like green-red can be used. Where quantitative information has to be given, digital presentation should be used in preference to the reading of graduated scales. Important control panel instruments should have preferably a combination of auditory (sound) and a visual warning signal scheme. Care should be taken to see that visual warning should be quite evident and not misleading. Lights or blinkers that are 30° from

the centre of vision will be noticed more slowly than lights that are centrally located.

Layout design of the equipments, control panels etc. should also keep in mind the need for their subsequent maintenance and repair in the beginning itself. Certain points which require regular maintenance should not be placed at inaccessible places. Diagnostic studies might have to be conducted to isolate causes of failure.

Rectification would be done accordingly. Ergonomics considerations need to be kept in mind at various design stages.

Instrument Display Design

We can think of display as any device or event which gives information about a situation which is occurring or has occurred. Where this information cannot be obtained by seeing or hearing directly, we might have to resort to the use of instruments, like pressure gauge for instance, which reveal the conditions of a piece of equipment or instrumental displays which could be primarily of auditory or visual type.

Visual dial displays could have a graduated scale on which the indication of a value is given by means of a pointer. There could be 'off-on' lights known as **indicators**, warning devices and numerically displayed **information counters**. Dials and counters may be used for quantitative and qualitative reading, and to check reading for comparison in visual displays without controls. As for the case when displays are used with controls, dials and counters may be used for check controlling, setting and tracking. Warning and indicator devices are used in both cases. Visual displays could be of different kinds like (i) moving index with a fixed legend (moving index display), (ii) fixed index with a moving legend (fixed index display), (iii) open window display, (iv) counters, (v) shutters, lights etc. Dials could be of shapes varying from circular to linear forms.

Studies conducted have shown that counters which give the value directly in numerals are far more superior than others for quantitative reading. The design of the actual scale on a dial, in case of a graduated scale, has far greater influence on accurate reading than its shape. Moving index displays are found to be superior to fixed index displays probably because additional information is given by the position of the index.

It has further been observed that vertical straight dials are better than circular dials because an upward movement of the pointer will always indicate an increase in value. However, for recording a rate of change, a circular dial is preferred because the angle of the pointer rapidly conveys the relevant information. Circular dials also find favour when comparisons need to be made. However, it has been suggested by various workers that moving pointer instruments are most suited for check reading. Horizontal straight dials can be used for setting machines more quickly as compared to other varieties.

However, when dials are mounted in panels with associated controls, it is probable that both circular and vertical straight dials may be used with reasonable confidence. There seem to be no definite conclusions about the variety of dials best suited for indication and warning purposes.

Readings 'at a glance' used in connection with quantitative reading implies a reading time of 1.0 to 2.0 seconds whereas check reading at a glance may be as short as 0.5 second. If 'x' is the percentage tolerance and an instrument is to be read to 100th of its maximum scale value (m.s.v.) and if a scale division is to be read to fifths, the optimum number of scale divisions in a whole scale would be $(100/5x)$.

Instruments and counters could be used for various purposes. It seems that when check reading alone is required, the shape of the instrument is not of vital importance. However, if a control movement is also involved, as in check controlling, then the movement of the instrument should be compatible with that of the control.

Displays could be pictorial when we wish to disseminate primarily qualitative information about a situation. These displays could include not only instruments but tables, graphic presentations and even pictorial panels. Today computer graphics is assuming great importance.

There could yet be another way of communicating information namely by auditory displays. The simplest use of auditory signals is for providing warnings of the 'yes-no' type. Yet another form of auditory display in addition to the above information gives some quantitative information, e.g. a chiming clock. To be effective the sound intensity of a warning device should be at least 10 decibels (dB) above the background noise. Intermittent sound catches attention more readily than continuous sound.

Compatibility

Now you will notice that there are quite a few natural movements. One usually turns a knob in a clockwise rotary direction or from left to right so as to switch on an instrument or equipment. Such natural movements need to be kept in mind while designing instrument knobs. Learning times for the operation of equipment on which controls are compatible with natural movements are much shorter than if the controls are incompatible. There will be greater risk of accidents in case of incompatibility.

Performance deteriorates on equipments with incompatible control movements.

While designing the control knobs, either have all of them compatible or all of them incompatible with the natural movements. Where controls are associated with dials in a panel, the dials and controls should be laid out with the same spatial relationship, e.g. the left hand dial should be operated by the left hand controls and so on. It is also important to know the preferred hand of an

operator. Unfortunately, most of the researches and recommendations have been made for the right handers only.

Control Design Characteristics

In the absence of a computer, controls are the normal way in which an operator conveys his instructions to a machine. It is therefore important to take note of the shape, size, inertia and friction characteristics of controls. The anatomy of the limbs used in operation could be considered while determining the best type of control for different uses.

Control used for continuous adjustment could be rotary or reciprocating in form. Cranks, handwheels and knobs are of the rotary type while 'joysticks' and levers are of the reciprocating form. Levers usually give control in one dimension and joysticks in two dimensions but both types of controls do give speed and accuracy. Controls required for discrete movement will usually be of some 'off-on' type of mechanism.

Let us now discuss some of these control mechanisms and their utilities.

Crank is a control in which the handle is offset from and parallel to the shaft. Cranks are used when high turning speeds are required upto 200 r.p.m. (revolutions per minute), when rapid complete turns are required and when heavy loads have to be moved manually.

Handwheel is a circular control gripped by the rim, preferably with both hands. Handwheels should be used when turning speeds are low (1 r.p.m. or less), when very accurate partial turns are required and when torque required is above 15 inch-lbs. Handwheels are best used when the amount of turn required does not exceed 90° for fine positioning movement.

A **knob** is a rotary control that can be operated freely by gripping it on both sides with the fingers of one hand. Knobs may be used for making fine adjustments when loads are light, or as rotary selector switches for switching operations.

A **lever** is a hand-operated rod-like control working in one dimension about a fulcrum. A lever should be used when the effective travel is small, when fast movement without great accuracy is required and when there is a medium to heavy load.

Toggle switches are miniature levers used as selector switches. However, they should not be used for more than three switching positions, and there should be between 30° and 40° of movement on either side of the central position. Toggle switches should not be used for making discrete adjustments.

A **joystick** is a lever working in two dimensions. Joysticks should be used when continuous simultaneous control is required in two dimensions or for rapid multiple switching operations.

A **rotary lever** is a lever attached to a shaft so as to permit a complete turn. It is used when a fairly high force is required over a long range of movement with fairly accurate end control.

A **pedal handgrip** is a rotary lever with a limited area of movement which is gripped close to the shaft rather than by its end. Handgrips are used for rotary multiple switching. They should not be used for continuous control.

A **pedal** is a reciprocating control operated by one foot acting independently. Pedals should be used when a very powerful force has to be applied or for continuous controlling when accuracy is not of a high order or for on/off or start/stop switching.

A **rudder bar** is a reciprocating control pivoted about its centre and operated by the foot in line with the lower leg. A treadle is a reciprocating control pivoted at or near its centre which is operated by the movement of the ankle. Rudder bars are used when accurate control is very important but the amount of force required is very small.

A **push-button** is a reciprocating control, small in size which has a positive action in one direction only. Push button should be used for switching in one or two senses only.

10.8 ENVIRONMENTAL FACTORS

Temperature and Humidity

Let us now discuss the effect of temperature and humidity on the performance of workers. Studies have been conducted both in laboratory settings as well as industrial settings yielding quite a bit of statistical data on accidents. In an investigation into loading of coal tubs in coal mining the results revealed that there was a slow but steady increase in the loading time (minutes) as the effective temperature increased from 19°C (66°F) to 28°C (82°F) as shown in Figure XI.

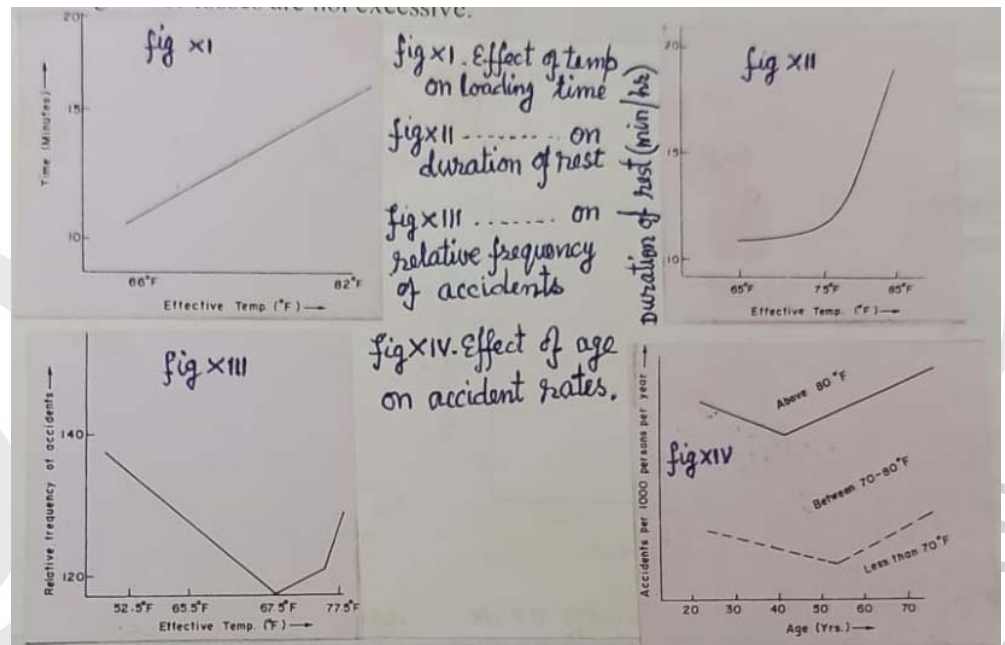
Moreover, the time taken for resting (minutes per hour) also increased rapidly for temperatures above 24° C (75° F) as can be seen in Figure XII. The working efficiency at the higher temperature was about 41% less than that at the lower.

Some studies were conducted in a weaving shed also. The average per hour output by 'pick count' on 44 looms fell from 7163 to 6832 when relative humidity (r.h.) of 77.5% to 77.9% rose to 82.5% to 84.9%. There, however, seem to be hardly any studies conducted on the performance of workers when temperatures are reduced. Some data on accidents in relation to temperature reveal a rather strange phenomenon. The studies conducted show an increase in accidents both with decrease and increase of temperature from an optimum of 65°F-69°F, the increase with cold being somewhat the greater as can be seen in Figure XIII.

Also, some studies were conducted on people with different ages to investigate the relative effect of temperature on efficiency. Now accidents could easily reflect, in some way, the effect of temperature on efficiency. As can be seen from Figure XIV, older men are adversely affected by higher temperatures.

Having noted the effects of temperature and humidity on performance, one should seriously consider providing an environment conducive to the worker so that he could perform effectively and efficiently. The body attempts to maintain a heat balance and a constant body temperature. This can be done as long as the regulating body mechanism is working within its capacity, and heat gains or losses are not excessive.

Heat could be gained by the body through convection (C), radiation (R) and



Heat could be gained by the body through convection (C), radiation (R) and the production of body heat through muscular activity and basal metabolism (M). Similarly, heat is lost through evaporation (E), convection and radiation. Therefore, the heat balance equation may be expressed as:

$$M \pm R \pm C - E = 0$$

$$\text{or } E = M \pm R \pm C$$

Now the rate of evaporation depends upon the sweating mechanism of the body and upon the relative humidity or water pressure of the environment in which the individual is working.

Should the body be gaining heat greater than it can lose by evaporation, then a maximum body temperature rise is about 1°C (or 2°F); otherwise severe heat stress could lead to heat stroke. It is possible, however, that man's tolerance to heat increases gradually with the passage of time.

Heat may be troublesome under two conditions: warm-moist and hot-dry. Warm-dry conditions do not pose a problem whereas in hot-moist climate it would be impossible to survive. In a warm-moist environment, heat is mainly convected. Work becomes difficult because of the high humidity which reduces evaporation of sweat though proper ventilation and air-conditioning can help in improving this situation.

However, where heat is radiated, amelioration of this condition will depend on preventing the heat from falling on the body or, where this is impossible, removing the workman from the environment at appropriate times to allow him/her to cool off.

Vibration

During work, a person could be frequently subjected to vibration from various resources. The effects of movement and vibration upon the person may range from motion sickness through slight discomfort to physical damage. Some studies have been conducted which reveal a relationship at the tolerable limit between the amplitude (A) and frequency (F) of a vibration as follows:

$-AF^3 = 2$ for low frequency vibration 1 to 6 cycles per second

$AF^2 = 1/3$ for medium frequency vibration 6 to 60 cycles per second.

and $AF = 1/60$ for high frequency vibration above 60 cycles per second.

Vibration which is at or near the tolerable comfort limit may be experienced for long periods without causing any harm, although it may interfere with a person's efficiency as an operator and produce sensations of fatigue. However, it should be noted that most of the experimental work on subjective tolerance to vibration have been of comparatively short exposure durations rarely more than about half an hour. Excessive vibration of amplitudes of the order of 0.2 at frequencies of about 10 to 20 cycles per second has been shown to cause damage to the lungs, rectal bleeding, blood in the urine and constipation in some cases. In some studies of injuries due to use of hand-held vibrating tools or pneumatic drills, instances have been reported of 'white fingers', 'dead hand' or 'Raymonds phenomenon'. However, it is difficult to make specific design recommendations which will ensure that the effects of vibration on efficiency are minimal. Not much attention is given to vibration because even the people/operators themselves feel that they are paid, in part at least, to tolerate discomfort (which can include that due to vibration). It appears most operators accept vibration provided it does not cause actual physical damage.

Noise

Let us now discuss yet another important environmental factor, namely, noise which can best be described as unwanted sound. Noise could be a frequent cause of fatigue and irritation resulting in loss of output. The ear is quite sensitive. The risk of damage to the ear appears to be greatest from frequency of sounds between 2,400 to 4,800 cycles per second. Hearing losses may

increase with age. For instance, at the age of 50 years, a hearing loss of 40 decibels might be expected above 12,000 cycles per second and 5 decibels at 125 cycles per second compared with the hearing of an individual of the age of 20.

Moreover, it has long been recognised that individuals who have been exposed to high noise levels over a long period of time will suffer a hearing loss. It is thought that people get used to noise without realising the long term impact. Still, quite a few noises produced intermittently could be very irritating and harmful. Any intermittent noise which approaches the damage risk level should be considered a potential hazard. In a number of countries abroad, deafness due to noise has come to be recognised as a compensatable industrial disability.

Protection against unavoidable noise may be provided by some form of earplugs, or simple cotton wool which might be a cheap and effective preventive remedy. It has been observed that noise above 90 decibels can induce the commission of errors in those who are normally accustomed to noise. Under certain circumstances, some individuals may become irritated by certain types of noises which in turn may have an effect on their work. High pitched noises of a frequency of above 1500 cycles per second appear to be more annoying than lower pitched noises of equal intensity.

Relating a subjective feeling such as annoyance to an objective measure of performance is as difficult as trying to relate, say, boredom to performance. However, at times noise could be made meaningful in some cases. It may be necessary to introduce sound artificially into quiet working places in order to act as a barrier between one worker and another. Some companies think of introducing music-while-you-work so as to increase output and to improve the workers' feeling of satisfaction in the job. However, it is possible that while some like music, there are others who do not like it and treat it as noise and hence show an adverse impact on productivity. Also superimposing music on an already high noise level in the work place and its environment could render the general noise level dangerous. Noise may also interfere with oral communication between persons. Shouting will permit communication at higher noise levels, but it could be very strenuous. Noise can also interfere with communication between man and his equipment by masking the sound of warning signals or bells. Where this is likely to happen, auxiliary visual signals should be considered.

There are various ways of reducing noise. Probably the most important method is the reduction of noise at the source itself. You could also think of isolating the equipment from the surrounding structure or its total enclosure to prevent the noise spreading, or by mounting noisy machines on resilient bases. Sometimes noise is produced by resonance when, for instance, parts are being ground or when office machinery is mounted in sheet steel cabinets. Suitable damping devices can often be attached to parts which are likely to resonate. Alternatively, damping material can be applied to the inner surface of the sheet

metal. If however all this has been tried to prevent production and distribution of noise from the source and the noise level remains still too high, some acoustic absorption will be necessary. Quite often residents staying close to some industries may find the noise very irritating. To absorb such noise, and also to reduce pollution, it is advisable to plant trees, which also add to the scenic and aesthetic view of the factory. Some of the prominent species of the plants and trees such as Bouga-in-velea, Vasantmalti, Neem, Ber, Ashok and peepal act as an effective screen against airborne particles and also act as a damper to absorb a great deal of noise intensity.

Visual Environment

The majority of industrial tasks will depend for their efficiency on adequate vision and, therefore, lighting arrangements may play an important role in determining the efficiency with which tasks are carried out. The standards of lighting and recommended levels of illumination at work place are good aids for work and job designers. It is said that at normal levels of illumination, the ability to see increases in proportion to the logarithm of the illumination (given in lumens per square foot, lm/ft^2 , $1 \text{ lumen}/\text{ft}^2 = 1 \text{ ft candle}$ and $1 \text{ lux} = 1 \text{ lumen}/\text{m}^2 = 0.09293 \text{ ft candle}$). This implies that from a practical and economic aspect, a point is reached at which large increases in illumination will produce relatively small increases in efficiency or output. One such study, conducted for a task requiring speed and precision, revealed that there was a significant decrease in errors when the illumination was increased from 5 to 50 lm/ft^2 . When the illumination was further increased to 150 lm/ft^2 , there was only a slight non-significant decrease in errors. However, the above study was conducted under certain conditions and the results just cannot be extended to all types of activity.

Apart from direct lighting standards, there are some other important factors which can affect performance. The contrasts between the surroundings and the task being performed, the colour schemes and the presence or absence of glare could greatly influence the overall efficiency and effectiveness of the work. For reading, high-contrast or well printed material in areas not involved in critical or prolonged seeing e.g., for conferring, interviewing etc., the recommended illumination is 10 lm/ft^2 . Recommended illumination is 100 lm/ft^2 for regular office work, reading good reproductions, reading or transcribing handwriting in pencil on poor paper, and sorting notes, etc. Fine bench work and machine work require 70 lm/ft^2 and 500 lm/ft^2 , and rough bench work and machine work 15 and 50 lm/ft^2 as recommended by Illuminating Engineering Societies (IES). However, people can adapt themselves to a variety of conditions so that they can work quite satisfactorily in conditions worse than those thought to be ideal. Sometimes level of illumination may be generally appropriate, the relative location of jobs, (e.g. overhang of press and position of the operation in relation to a luminaire) may be such that the light actually falling on the task may be quite inadequate.

The amount of light required for the performance of a visual task is influenced by four factors which are inter-dependent. These are (a) the size of the object, (b) the contrast between the object and its immediate surrounding, (c) the reflectivity of the immediate surroundings, and (d) time allowed for seeing. However, with the steady increase in the number and brightness of lighting fixtures these days, the problem of glare is causing concern. There could be a discomforting glare which produces a feeling of strain due to the worrying effects of sources of brightness. On the other hand, there could be disability glare which could cause a diminished ability to see. The effect of both types of glare may cause distraction by drawing the eyes away from the visual task. Reflections could be from paper surfaces, cover glasses over dials or shiny panel surfaces. Table 4 shows some recommended maximum brightness ratios and reflectance values.

Table 4 Recommended Brightness Ratios and Reflectance values

Maximum Brightness Ratios	Range
Between jobs and adjacent surroundings	5 to 1
Between jobs and more remote surfaces	20 to 1
Between light sources (or sky) and sources adjacent to them	40 to 1
Any where within the environment of the worker	
Type of surface	Reflectance values
Ceiling	80
Walls	60
Desk and bench tops	35
Machines and Equipment	25 to 30
Floors	Not less than 15

Yet another important factor that could effect worker's performance is the colour scheme. It is often said that warm saturated colours such as yellows and reds tend to give a sense of warmth and an advancing effect. Conversely, cool shades of blues, greens and greys tend to give a sense of coldness and recession. Long narrow rooms may be made to appear wider by using 'cool' colours on the side walls and 'warm' colours on the ends. Light of special colour may with advantage be used to improve visibility by a selective darkening of parts of the task. Moreover, a light source should not keep flickering. Flickering lights could be a source of irritation and watering of the eyes and may produce sensations of muscle twitching such as eye blinking and facial twitching, sensations relating to other parts of the body such as 'funny' feelings in the stomach, headache, nausea, chill and tense muscles etc. Hand- eye coordination is significantly impaired by flickering light to the tune of about 10 flashes/sec.

Planning for visual efficiency should start at an early stage in job planning. As a general rule, sunlight is preferable to artificial lighting. Apart from the work place, suitable lighting should also be provided in all important stairways, exits from work places and passages to these. A great deal can be achieved by

good lighting, the use of colour, by the manipulation of contrasts to make a work place in the factory or office, a pleasant place where people will be happy to work and perhaps become more effective and efficient. The money, time and thought devoted to achieving good visual conditions at a place of work is certain to yield good dividends in the long run.

10.9 ORGANISATIONAL FACTORS

The problem of when to give a 'break' or 'rest pause' to an operator has been engaging the attention of researchers for many years. Work measurement techniques are important, some of which were discussed in the previous unit. Heavy work can be measured by means of energy expenditure. Researchers have arrived at a reasonable estimate for the calorie expenditure of an 'average man' employed in different types of occupation. It has been estimated that the light work clerks expend about 2,800 K.cal per day whereas coalfield miners expend about 3,600 K.cal per day. On an average the person working over an extended period should not expend over 3,200 K.cal per day. If heavier work is undertaken, the daily expenditure will rise. Work physiologists seem to agree that over a period of time, the calorie output of a normal man in good health should not exceed 4800 K.cal. per day. The whole day's activities are divided broadly in three stages, namely, time spent in (i) bed (ii) work activity and (iii) non-work activity. As such, it is estimated that about 2000 K.cal could be used for a normal days work. A value of 5 K.cal/minute seems to be acceptable to workers and work physiologists. The approximate number of calories required per minute for activities is shown in Table 5.

Table 5 Expenditure in Cals/min for various activities

Type of activity	Energy expended cals/min	Type of activity	Energy Expended cals/min.
Sitting at rest	1.7	Ironing	4.4
writing	2.0	Heavy assembly work	5.1
Typing	2.3	Chopping wood	7.5
Medium Assembly work	2.9	Digging	8.9
Shoe repair	3.0	Tending furnace	12.0
Machinery'	3.3	Walking upstairs	12.0

Table 6 is a rough grading of work difficulty in terms of calories and heart rate.

Table 6 Grading of work on physiological considerations"

Work load	Energy expenditure cals/min	Heart rate beats/min
Very Light	Less than 2.5	Less than 75
Light	2.5 – 5.0	75 – 100

Moderate	5.0 – 7.5	100 – 125
Very hard	7.5 – 10.00	125 – 150
Extremely hard	10.0 – 12.5	150 – 175

The optimum arrangement for work and rest is that work should cease at the point in time at which lactic acid (responsible for muscle fatigue) starts to accumulate in the body; rest taken at this time will be minimal. When a substantial part of the work is carried out at a rate exceeding 5 K. cal/min, the cycle of work should be organised into periods of about 10 minutes activity and 7 minutes rest if the optimum output and minimum fatigue are to result. The working hours need to be interspersed with some pauses, rest period and meal breaks etc.

Thus far we have discussed fatiguing in case of heavy work. In the case of light but repetitive work, the operator's work may lead to boredom instead of fatigue. In such cases, to motivate the operator one might have to redesign the jobs and think in terms of job enrichment and job enlargement. Let us now look at some behavioural dimensions of job design.

10.10 BEHAVIOURAL DIMENSIONS OF JOB DESIGN

Traditionally, jobs have been designed to minimise immediate cost and maximise immediate productivity. We agree that economic criteria are still paramount. We must not forget that behavioural implications in job design can and do influence performance. With this goal in mind, let us examine the behavioural ideas of job enlargement, job enrichment, job rotation and participative job design.

Jobs are a set of tasks, each task being associated with a set of stimuli-auditory, visual and/or tactile (affecting the sense of touch). A job consists of varied tasks provides varied stimuli; a job with routine repetitive tasks usually provides few stimuli.

Job Enlargement

If jobs become too specialised, workers perceive their job to be monotonous and boring, and this leads to job dissatisfaction. Many workers become alienated and the result is high levels of tardiness, absenteeism and turnover. Under such situations we should think of **job enlargement**. An enlarged job would offer the employees opportunities such as (i) a larger variety and hence the opportunity to use a variety of skills (ii) autonomy, the opportunity to exercise control over how and when the work is completed, (iii) task identity, the opportunity to be responsible for an entire piece or programme of work and (iv) feedback, the opportunity to receive on line information. Thus **job enlargement is the procedure of redesigning jobs or modifying work so that employees can feel more involved in and responsible for what they do.**

Job Enrichment

Alternatively we could think of **job enrichment**. It presumes that many jobs are so highly specialised that operative workers can no longer visualise how their work contributes to the organisation's goals. The worker tightening a nut on a bolt all day long loses sight of the fact that this nut helps hold a wheel on a new automobile and thereby provides safety for some new owner. **Job enrichment is a procedure of redesigning work content to make the job more meaningful and enjoyable by involving employees in planning, organising and controlling their work.** Management must supply information on goals and performance that previously was not available to the workers. A proper organisational climate has to be established for success. For some workers, enrichment might reduce social interaction. Many employees prefer a low level of required competency, high security and relative independence to the increased responsibility and growth that job enrichment implies.

Job Rotation

This involves movement of employees into a job for a short period of time and then make them out again.

Yet another way to approach jobs that cannot be designed or automated to eliminate undesirable features is to move or rotate employees into the job for a short period of time and then move them out again. This **job rotation** technique seems to be working well in a large number of situations that seem to defy job enrichment and/or enlargement.

However, one very important fact overlooked by designers is the person/operator who performs the job. If the ultimate beneficiary, the person/operator could be involved in a participatory design procedure, there would be greater success in implementing any changes that need to be done in the organisation.

10.11 SOCIO-TECHNICAL APPROACH TO JOB DESIGN

The consideration of both the technology of production and the social aspects of the work environment is called the socio-technical approach to job design. What is sought, is a design that provides for high levels of productivity and quality and at the same time ensures a satisfying job and work environment. The socio-economic approach emphasises the need for integrating the social consequences of work with the traditional cost versus quantity considerations of production. The concept of socio-technical systems was first elucidated by Eric Trist and his colleagues at the Tavistock Institute of Social Research in London.

On the basis of studies carried out at the Tavistock Institute, the following guidelines for job design are offered at the level of the individual:

- 1) Optimum variety of tasks within the job.

- 2) A meaningful pattern of tasks that gives each job a semblance of a single, overall task.
- 3) Optimum length of work cycle.
- 4) Some scope for setting standards of quantity and quality of production and a suitable feedback of knowledge of results.
- 5) Inclusion in the job of some of the auxiliary and preparatory tasks.
- 6) Inclusion in the job of some degree of care, skill, knowledge or effort that is worthy of respect in the community.
- 7) Perceivable contribution of the job to the utility of the product for the consumer.

Some group level guidelines are:

- 8) Providing for 'interlocking' tasks, job rotation or physical proximity where
 - a) there is a necessary inter-dependence of jobs for technical or psychological reasons.
 - b) the individual jobs entail a relatively high degree of stress.
 - c) the individual jobs do not make obvious, perceivable contribution to the utility of the end product..
- 9) If a number of jobs are linked together by interlocking tasks or job rotation, they should, as a group, have some:
 - a) semblance of an overall task that makes a contribution to the utility of the product,
 - b) scope for setting standards and receiving knowledge results, and
 - c) control over the 'boundary tasks':

Some caution is, however, needed in implementing the above guidelines. For example, a 'loose rein' situation of forming and functioning of autonomous groups might not be tolerated by certain job designers. Sufficient amount of top management support might be needed to make traditional job designers 'toe the line' of a socio- technical perspective.

10.12 SUMMARY

Work design is concerned with the study and design of any type of management or work system in any type of organisation. We have noted the historical trends in the management of work and the need for adopting a scientific, systematic and integrated approach to work design so as to have increased productivity leading finally to enhanced human dignity and a better quality of life. A generalised approach of 8 basic steps of work study have been

mentioned. Some of these steps are then discussed in detail while discussing method study and work measurement. Various charts have been discussed which would help you in the 'record stage' of method study. A critical examination technique checklist has been provided to aid you in examining and developing methods. Work measurement techniques, especially time study and work sampling, have been discussed at length. Before setting standards, you must take note of the 'learning curve' phenomena. Work study applications show that the technique can be effectively applied to a large variety of situations; it is not just limited to the manufacturing sector.

A key function in production and operation management is organising work. This is essentially work and job design. We have examined a number of important issues regarding the design of jobs and have developed certain useful tools of job analysis and productivity improvement. In considering the role of people in work, operation managers must take a socio-technical approach; that is, they must consider not only the technical aspects but also the social atmosphere of the job. In addition to work design methods, human engineering/ergonomic considerations need to be kept in mind while examining the physical workplace, the physical environment and the social environment.

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10.13 KEY WORDS

Activity chart: Divides operations into major task segments performed by workers and machines; times them to determine idle and productive times; appropriate for routine, repetitive task with worker-machine interaction.

Allowed time: The basic or normal time plus allowances for fatigue and delays.

Flow process chart: Analyses interstation activities to capture the flows of products through the overall production process.

Learning curve: Pattern of input resources consumed in creating successive units of a product; generally initial units require higher amounts of inputs (time), and later units require progressively fewer inputs.

Method study: The systematic recording, analysis and critical examination of existing and proposed ways of doing work and the development and application of easier and more effective methods.

Multiple activity process chart: A form of process chart recording the related sequence of work of a number of operators and/or machines.

Open system: A system that is an integral part of a larger system; its viability depends upon successful adjustments to varied inputs from and outputs to its environment.

Process chart: A graphic representation of a sequence of events that occur in the work method, classifying them by symbols according to the nature of the events. It is a device for visualising a procedure for the purpose of improving it.

Rating: The mental comparison, by a work study man, of the performance of an operator under observation with his own idea of a standard performance for a given method.

SIMO chart: A chart used to record against a time-scale the **therbligs** performed by an operator or operators at work; showing each therbligs by colour, sequence and duration, together with the parts of the body or machine affected by them.

Standard minute: The unit of measurement of output of work. It represents the output of work in one minute of the allowed time for any given operation.

Standard time: The allowed time which is determined to be necessary for a qualified worker, working at a pace which is ordinarily used under capable supervision and experiencing fatigue and delays, to do a defined amount of work of specified quality when following the prescribed method.

Time study: A measurement technique for determining as accurately as possible, from a sufficient number of observations, the time necessary to carry out a given activity at a defined standard of performance.

Two-handed process chart: A form of operator process chart recording the work of both the operator's hands.

Work cycle: The complete sequence of the elements necessary to perform a specified activity or task or to yield a unit of production. It may include elements which do not recur in every cycle.

Work measurement: The application of techniques designed to establish the work content of a specified work tasks by determining the time required for carrying it out at a defined standard of performance by a qualified worker.

Work sampling: A work measurement technique that involves defining the condition 'working', sampling the activity 'overtime', and computing proportion of time the worker is engaged in 'work'.

Work study: A term used to embrace the techniques of method study and work measurement which are employed to ensure the best possible of human and material resources in carrying out a specified activity.

Anthropometric data: Data regarding physical characteristics of human beings.

Job Design: The determination of specific job tasks and responsibilities, the work environment and work methods.

Job Enlargement: Procedure of redesigning jobs or modifying work content to provide greater stimulus variety, autonomy, task identity and feedback for the worker.

Job Enrichment: Procedure of redesigning work content to give more meaning and enjoyment to the job by involving employees in the planning, organisation and control of their work.

Job Rotation: Movement of employees into a job for a short period of time and then out again.

Human factors engineering/Ergonomics: A field of study concerned with the abilities and limitations of human beings in the design of tools and work places.

Principles of Motion Economy: General statements focusing on work arrangement, the use of human hands and body, and the use of tools.

Therblig: One of 18 elementary human motions such as grasp, select, assemble and so on so forth.

10.14 SELF-ASSESSMENT EXERCISES

- 1) It is usually presumed that 'resistance to change is a characteristic attributed to people'. What would be your personal reactions, if some work design analyst came to your work station to conduct a study of your work.
- 2) Place six piles of foolscap paper before you, then collate sets of six in order and staple them. How would you place the piles? Make a chart of the method you used. If you had to do this by the thousands, what improvements in method can you suggest? Develop an improved method.
- 3) **Time study problem:** Determine the standard time for the following job. Add 20% for allowances. The times shown are continuous stop-watch readings in hundredths of a minute.

←———— Cycle —————→

Element	1	2	3	4	5	6	7
a) Get two cases	10	-	54	-	04	-	52
b) Put part into case	21	40	64	82	15	33	59
c) Fasten parts into position	28	47	72	96	22	40	81

Performance rating of the elements a, b and c were 105%, 115% and 95% respectively.

[Follow example 3]

- 4) **Man-machine chart problem:** Consider one person operating two semi-automatic machines. The cycle consists of:

- a) load machine -45 seconds
- b) machine part -90 seconds
- c) unload machine - 30 seconds

The two machines are alike, and each completes the machining operation and stops automatically. Assuming that both machines are empty, at the start, draw a man- machine chart for four such cycles. What do you infer from the chart? Make your recommendations accordingly.

- 5) **Man-machine chart problem:** Now if there is a large volume item and several semi-automatic machines are in operation, an operator can operate several machines. If the machines do not, however, stop after they have finished their operations, the operator must be there to take out the finished pieces. The time it takes for one of the operations needed to make the item is: unloading machine 0.2 minutes, loading machine 1.7 minutes and machine time is 7.0 minutes. You may assume that the machines are so close together that the time it takes to go from one machine to the other can be neglected.
- i) How many machines can a person operate? Draw up a worker machine chart showing how your plan works.
 - ii) Suppose that in answer (i), you have to concern yourself with costs and suppose that a worker costs Rs. 12.00 a minute and machine's idle time costs Rs. 15.00 a minute. Is the answer still the same? Justify.
 - iii) If there were a large number of machines, is there any way to eliminate the idle time of both machines and workers?
- 6) **Work sampling problem:** A work sampling study revealed that out of a total number of readings, 1050 taken thus far, the number of times a machine was idle was 345. If the limit of error required is to be 2 per cent for 95 cases in 100, how many more readings are required?

[Ans:N=18950]

- 7) **Work sampling tour schedule problem:** Given the following random numbers, can you design a tour schedule for taking 25 observations for a work sampling study. Assume an 8-hour observation period.

Column	1	2	3	4	5
Row					
1	03991	10461	9371 6	16894	98953
2	038555	95554	32886	59780	09958
3	17546	73704	92052	46215	159917
4	32643	52861	95819	06831	19640
5	69572	68777	39510	35905	85244

Hint: Go row-wise choosing two numbers at a time. The first four numbers would therefore be 03, 99, 11, 04 (starting from first row column).

- 8) Define job design. How has management viewed job design since the industrial revolution?
- 9) List the important factors that must be addressed in job design and briefly discuss the importance of each one.
- 10) Discuss some of the aspects involved in designing a workplace.
- 11) Contrast job enlargement and job enrichment. Are they mutually exclusive?
- 12) Each of us realises that such environmental variables as temperature and noise affect our work. What empirical evidence can you cite that supports the impact such environmental variables have on output?
- 13) What do you understand by the term 'a socio-technical system'? Can you give some socio-technical guidelines for job design?
- 14) Discuss some principles of motion economy and their relevance to job design.
- 15) What do you mean by ergonomics? Discuss briefly design of equipments as related to it.
- 16) Explain the various issues need to be considered while designing a job.
- 17) Discuss various environmental factors that effect productivity of a labour. How can you improve these? Give examples.
- 18) What are the factors that cause organizations to redesign their products or services? Describe some of the ways a product designer can use CAD.
- 19) Discuss the following factors for an effective job design
 - (a) Technological Factors.
 - (b) Environmental Factors.
 - (c) Organizational Factors.
 - (d) Behavioural Factors.

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UNIT 11 VALUE ENGINEERING AND QUALITY ASSURANCE

Objectives

Upon completion of this unit you should be able to:

- understand the concept of value engineering, differentiate between value and cost, see value engineering in historical perspective and appreciate the role of value engineering in cost reduction and performance improvement
- identify poor value areas in products and systems, learn about the value engineering job plan, appreciate the role of some of the techniques of value engineering, study some cases to see the improvements in product value through value engineering techniques and identify the behavioural and organisational issues involved in value engineering.
- appreciate the role of quality control, quality assurance and quality assessment, design a single sampling plan, draw an operating characteristic curve for a given single sampling plan and compute the AOQL
- assess process variability, draw up an $\bar{X}$ and R Chart and decide whether a process is in control or not.

Structure

- 11.1 Basic Concepts in Value Engineering
- 11.2 Historical Perspectives
- 11.3 Functions and Value
- 11.4 Value Engineering Job Plan
- 11.5 Fast Diagram as Value Engineering Tool
- 11.6 Some Case Studies in Value Engineering
- 11.7 Behavioural and Organisational aspects of Value Engineering
- 11.8 Benefits of Value Engineering and concluding Remarks
- 11.9 Introduction of Quality Assurance
- 11.10 Concept of Quality
- 11.11 Cost of Quality
- 11.12 Quality Management
- 11.13 Quality Organisation
- 11.14 Acceptance Sampling
- 11.15 Process Control
- 11.16 Use of Computers in Quality Control
- 11.17 Summary

11.1 BASIC CONCEPTS IN VALUE ENGINEERING

Value Engineering and Value Analysis

Value Engineering (VE) or Value Analysis (VA) is an important and powerful approach for improvement in the performance of the products, systems or procedures and reduction in costs without jeopardising their function. The terms VE and VA are used almost interchangeably. Other terms used to convey the same concepts are Value Assurance and Value Management (VM).

L.D. Miles defined Value Analysis in his book Techniques of Value Analysis and Engineering (1961) as **"an organised creative approach which has for its purpose the efficient identification of unnecessary cost i.e., cost which provides neither quality, nor use, nor life, nor appearance, nor customer features"**. Various other definitions are proposed such as "an organised systematic study of the function of a material, component, product or service, with the objective of yielding value improvement through the ability to accomplish the desired function at the lowest cost without degradation in quality". Thus the basic objective of VE/VA is to achieve equivalent or better performance at a lower cost while maintaining all functional and quality requirements. It does this largely by identifying and eliminating hidden, invisible and unnecessary costs. We may simply perceive VE as the systematic application of recognised techniques to identify the functions of a product or service and provide those functions at the lowest total cost.

Value Engineering should not be treated as a mere cost reduction technique or cheapening of the product. It is more comprehensive and the improvement in value is attained without any sacrifice in quality, reliability, maintainability, availability and aesthetics, etc. It was traditionally applied in the area of hardware projects, such as product design, though these concepts are equally applicable in software projects, in the systems and procedures. Recently these concepts have been applied to non- traditional areas such as urban slum development programmes, staff welfare motivation enhancement and courtesy improvement plans.

Reasons for Poor Value

One of the important reasons behind poor value in products, systems and procedures that we come across is the lack of organised effort in devising such systems. Many times the designs are created under highly compressed time frame and the designer may play safe by giving product designs with sole emphasis on technical feasibility and may prescribe thicker, costlier materials

and other unnecessary features which are not needed by the customer. Sometimes, ad hoc decisions get permanency due to lack of review of product designs. Often lack of consultation with others contributes to poor value. Lack of information, wrong beliefs, habits and attitudes are some of the other reasons.

Distinction between VE and Cost Reduction

Value Engineering	Conventional Cost Reduction
1. It is function oriented.	1. It is item oriented.
2. It applies innovative approach and ideas.	2. It follows past practices.
3. It exercises maximum creativity.	3. It is analytical in approach.
4. There could be divergent-convergent ideas.	4. There is only convergent ideas.
5. There is cost visibility on the following functional basis : — Basic function. — Secondary function. — Unnecessary function. — Essential function.	5. There is cost visibility on the following parameters. Part/component-wise. — Processwise. — Materials. — Labour. — Overhead. — Transport. — Packaging. — Maintenance. — Replacement. — Miscellaneous.
6. There is teamwork approach and spirit among members.	6. Usually there is individual approach and no team spirit.
7. There is multi-disciplinary approach.	7. There is generally no multi-disciplinary approach.
8. The V.E. approach does not compromise with performance, quality and reliability.	8. There is a tendency toward compromising quality and reliability.
9. It is a systematic and sequential approach.	9. Its approach is arbitrary and adhoc.

11.2 HISTORICAL PERSPECTIVE

Value Engineering had its origin at the General Electric Company (GEC). As a result of World War II, many materials were in short supply and L.D. Miles was associated with a committee to identify substitute materials without sacrifice in quality and performance. He organised a formal methodology in which a team of people examined the functions of products manufactured by GEC. Through team-oriented creative techniques they made changes in products to lower their cost without affecting their utility and quality. This methodology was given the name Value Analysis (VA). L.D. Miles who wrote his book in 1961 is generally recognised as the father of Value Engineering. Miles found

that many of the substitutes used were providing equal or better performance at lower costs.

The first organisation to initiate a formal VE programme was Navy Bureau of Ships in 1954. In 1959, Society of American Value Engineers (SAVE) was set-up to propagate the philosophy of Value Engineering. Many companies in USA, UK, Japan, etc. subsequently set-up formal VE programmes. The Department of Defence in US encouraged application of VE in defence projects.. A number of success stories of VE/VA are reported.

In India, VE/VA is now a well recognised programme and many organisations in military and navy as well as in other public and private sectors have set-up directorates or cells of Value Engineering. A professional society Indian Value Engineering Society (INVEST) came up to create awareness in VE/VA and they publish a journal, organise conferences and provide other services. It is now considered as an effective management tool.

11.3 FUNCTIONS AND VALUE

Types of Values

The term 'Value' is used in many different ways and is frequently confused with the monetary price or cost of an item. However value is not synonymous with cost.

Value may be perceived as the ratio of the sum of positive and negative aspects of an object. Thus value can be considered as a composite of quality and cost. It is more in terms of worth or utility. Thus a ratio of quality to cost can be treated as the value of a product. If its costs can be reduced for same quality or quality can be improved with same cost, then the value improvement can be said to occur. The term value can be divided into following types:

- a) **Use Value:** The properties and qualities which accomplish a useful purpose or service.
- b) **Esteem Value:** The properties, features or attractiveness which cause us to want or own it.
- c) **Cost Value:** The sum of labour, material and various other costs required to produce it.
- d) **Exchange Value:** The properties or qualities which enable us to exchange it for something else we want.

Function:

Function is the basic purpose of an item or an expenditure. It may also be a characteristic that makes the item work or makes it sell. **Miles defines function as: "The basic purpose of each expenditure whether it be for hardware, the work of a group of men, a procedure or whatever is to accomplish a function".**

Types of Functions

VE discipline deals with the functions of items, products, systems and procedures. It is a functional approach, a customer-oriented approach. Identification of the functions, therefore, constitutes an important aspect of VE. The term function' is used to mean the purpose or use of a product.

Functions can be of two types:

- a) Basic functions-the primary purpose of a product.
- b) Secondary functions-Other purposes not directly serving the primary purpose but supporting it. Many a time poor value may result in, because the functions have not been precisely understood and redundant or unnecessary functions have been imposed (see example 11.2)

Value Tests

VE is essentially a questioning attitude looking at the function and costs. L.D. Miles designed a set of value tests to ascertain whether there is a scope for value improvement. If these value tests are honestly applied, there is bound to be room for improvement in most of the products, systems and procedures that we come across. Some of these questions which can work as thought-starters for developing better value alternatives could be as follows:

- 1 Can the design be changed to eliminate the part?
- 2 Can you purchase it at lower cost?
- 3 Does it need all its features?
- 4 Is there anything better for the intended use?
- 5 Can a usable part be made by a lower-cost method?
- 6 Can a standard part be used?
- 7 Is it made on proper toolings considering the quantities involved?
- 8 Are there any newly developed materials that can be used?
- 9 Can two or more parts be combined into one?
- 10 Can any specifications be changed to effect cost reduction?

Identification of Poor Value Areas

By applying the value tests we may come across poor value areas which are responsible for unnecessary costs. These could be in the design of the product, , procurement, handling and storage of materials, production processes, packaging and distribution of the final product. Once we are able to identify poor value areas, we can focus our attention on these so this these unnecessary features can be eliminated

Another way to identify the poor value areas is through function cost matrix approach. If a function is relatively less important but accounts for a larger percentage of product cost then it is a potential area for value improvement. By determining alternative cheaper ways to achieve that function we can reduce the cost and improve value.

In simple terms a soundly conducted Value Analysis programme should essentially provide answers to the following questions:

- 1) What is the item?
- 2) What does it do?
- 3) How much does it cost?
- 4) Can anything else do the same thing?
- 5) How much does that cost?

11.4 VALUE ENGINEERING JOB PLAN

Value Engineering Process

As mentioned earlier, the major advantage of the approach is that it is a systematic and organised approach that examines all aspects of a problem employing a questioning attitude. Thus a formal approach has to be adopted to go through the VE programme. This formal procedural model of VE process is called VE Job Plan. In the beginning, when Miles proposed VE Job Plan, it was just a modified form of the steps involved in work study. Subsequently, it has been modified and a number of approaches have emerged which are essentially similar. These job plans have various steps and phases with their associated VE techniques at each phase. In one of the job plans the seven steps involved are: (1) preparation, (2) problem selection, (3) information, (4) evaluation, (5) creation, (6) selection and presentation, and (7) implementation and follow up.

In this unit we shall briefly outline the salient features of three different approaches to conduct a VE programme. These are:

- a) Job Plan due to Mudge
- b) DARSIRI method
- c) FAST (Function Analysis System Technique)

Since the Job Plan due to Mudge is a very well recognised approach, we will deal with it in this section. The seven phases of Job Plan are:

- (A) General phase
- (B) Information phase
- (C) Function phase

- (D) Creation phase
- (E) Evaluation phase
- (F) Investigation phase
- (G) Recommendation phase.

Each of these phases comprises or is supported by one or more techniques. There are work-sheets for each phase. The practice of Job Plan and the application of VE techniques should be made on properly selected project. Thus selection of VE project is important. Those products should be chosen for the study which are significant in terms of cost reduction potential. In step-by-step application of the Job Plan the project unfolds from the information phase right up to recommendation phase.

The general phase plays vital role throughout and provides a good base for other phases to succeed.

Brief description of each phase together with associated VE techniques are given in the following sub-sections.

(A) General Phase

Throughout the application of the entire Job Plan the techniques of this phase must be diligently applied to create the right environment for Value Engineering job plan to be effective. There are five techniques associated with this phase:

- a) **Use good human relations:** It will be seen that considerable personal contact is necessary throughout the Project. The use of good human relations means assistance in place of resistance.
- b) **Inspire team work:** This is one of the easiest to talk about, yet one of the hardest to accomplish. It calls for subordinating personal prominence or ego in the interest of the group as a whole.
- c) **Work on specifics:** We should avoid generalities and work on specifics. Concrete data and information on specific problems must be secured. Only opinions and hearsay can be expected when talking in generalities.
- d) **Overcome roadblocks:** In any organisation a group of dissenters can be found. These individuals knowingly or unknowingly, will use every means at their command to resist change. It is important to be able to recognise roadblocks and then take steps to overcome them. Mudge has in fact compiled an impressive list of 'killer phrases' which people use to kill an idea. It is very crucial to avoid such mental roadblocks
- e) **Apply Good Business Judgment:** Business decisions and judgments must be based on facts. Poor business decisions and poor judgment become prevalent when personal opinions and feelings take control. To apply good business judgment one must be resourceful, able to think and should be able to pursue new knowledge.

With the general phase as the base of foundation of the job plan, we can enter the second phase — information phase. The techniques included in the second phase, though seemingly simple, incorporate some of the most difficult portions of the approach.

(B) Information Phase

The objective of this phase is to gain an understanding of the project being studied and to obtain all essential facts relating to the project as also to estimate the potential value improvement. This phase comprises of three techniques:

- a) **Secure facts:** Information gathered must be authentic; it is one of the most arduous tasks. The type of information required will be:
 - i) Technical specifications-dimensions, grades, tolerances, quality, appearance.
 - ii) Environmental specifications- test conditions.
 - iii) Engineering drawings.
 - iv) Production sample-actual or model of it.
 - v) Production data-operations, speeds, rates, output and stock levels.
 - vi) Cost data-material, labour, overhead-costs.
 - vii) Work specifications-work place layout, standard times.
 - viii) Features preferred by Customers.
 - ix) Development, testing and service records.
 - x) Quantities involved.
 - xi) Scrap rates.
- b) **Determine costs:** In order to direct towards those areas promising the greatest return on time and efforts in VE, the complete and accurate costs must be secured.
- c) **Fix Costs on Specifications and Requirements:** By establishing a relationship between the costs and the specifications and requirements, a means is presented by which the latter two can be quantitatively evaluated. Extreme care should be taken during this phase to be sure that true facts are gathered, accurate costs are secured, and these costs are truly related to the specifications and requirements.

Once the techniques of the information phase have been used to secure pertinent data, the function phase of the Job Plan can be used.

(C) Function Phase

The objectives of this phase are to define the functions that a product actually performs and is required to perform as well as to relate these functions to the cost and worth of providing them.

The two techniques of this phase are a major part of the functional approach. When combined with the other techniques of the Job Plan it produces a systematic approach which is different and more productive than any other product improvement or cost reduction approach.

The two techniques of this phase are:

- a) **Define function:** This is one of the most crucial stages in Value Engineering. The method of functional analysis requires functions to be described with only two words, a verb and a noun. By so restricting the functional specifications, clear descriptions of the functions are possible. Concise function descriptions reduce the possibility of a detailed semantic elaboration. They force a rational approach by eliminating superfluous frills. The rules of function description are:
 - i) Determine user's need for a product or service.
 - ii) Use only one verb and one noun. The verb should answer the question "What does it do?" The noun should answer "What does it do"? Where possible, noun should be measurable and verb should be action oriented.
 - iii) Avoid passive or indirect verbs.
 - iv) Avoid goal-like words or phrases, such as improve, maximise, minimise, optimise, etc.
 - v) List a large number of two-word pairs and then select the best pair.

Example 11.1: Some functional definitions are:

Product	Function
a) Mirror	Reflect light
b) Brake	Arrest motion
c) Clutch	Transfer power
d) Erection tube cover	Shield Tube
e) Cigarette lighter	Provide ignition
f) Light bulb	Emit light
g) Screwdriver	Transfer torque
h) Coffee cup	Hold Liquid.

- b) **Evaluate Function Relationship:** This technique attempts to determine relative importance of various functions. Through this technique a descending order of importance of the functions is established along with the relative value of their importance.

A paired comparison technique to determine the numerical value of various functions is very simple and effective to use. In this, pairs of functions are compared and it is sought to determine which is more important and whether

the degree of variation is major, medium or minor. Suppose we are comparing A with B. Then A-3 will mean that A is more important than B and there is a major difference in their importance. B-1 would have meant that B is more important than A but there is a minor difference only. This way a total number of $n(n-1)/2$ pairs are compared and values entered in a cell if n-functions are to be compared. Then the score is obtained by adding all the numerals following a particular function. The function score divided by the total score gives relative importance of that function.

Function description should be derived for the product and all its components. The evaluation process also helps to find out whether it is a primary (basic) function or a secondary function. The basic function will have the highest score in the above- mentioned process of evaluation. The technique not only establishes the basic and secondary functions but also identifies those functions which are present because of specifications and requirements or present design approach. Generally, a product or component will have only one basic function and a number of secondary functions. If you have more than one basic function, it must be a mere restatement of the other.

Example 11.2: Here we illustrate the application of function phase on the item. 'Door Assembly' of a refrigerator. The two-word definition of each part or component of the door assembly is shown in Table 1 in the form of Functional Analysis Worksheet. The paired comparison of various functions is shown in Table 2. Figure I shows the graphical display of the relative importance of various functions which identify them as basic and secondary. You can also distinguish functions which are there due to present design approach as well as due to specifications and requirements. The basic function of the door assembly emerges as 'Provide Security' with the highest score.

Having defined the functions, the next step is to establish the worth of each function. The objective is to determine the poor value functions and to obtain a reference point from which the cost of alternatives can be compared.

Function cost matrix is an effective technique of finding out the relative importance of a function and the percentage cost incurred in attaining that function. If the importance is low and cost is high then it reflects a poor value area.

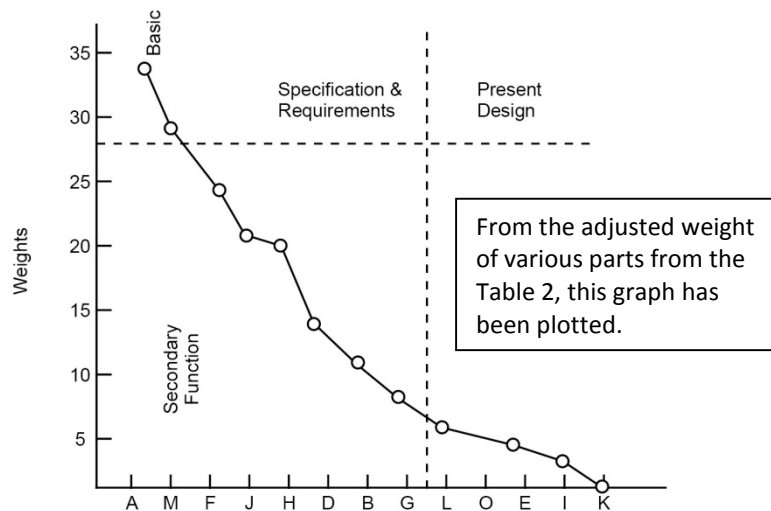


Fig. 1: Weight factor vs. function

Table 1: Functional Analysis Work Sheet (for Example 11.2)

Qty	Description	Function		Part		Assembly	
		Verb	Noun	Basic	Sec	Basic	Sec
1(A)	Outer Pan	Provide	Support		X		
		Provide	Security	X		X	
		Permit	Rotation		X		
		Provide	Appearance		X		
4(B)	Gusset Plates	Provide	Strength	X			
1(C)	Handle	Provide	Location	X			
	Reinforcement	Provide	Stiffness		X		
1(D)	Centre Stiffner	Provide	Stiffness	X			
1(E)	Lock Assembly	Provide	Fastening	X			
2(F)	Sleeve door Hinge	Provide	Location		X		
		Provide	Rotation	X			
		Support	Weight		X		
1(G)	Handle	Facilitate	Grip		X		
		Facilitate	Opening	X			
1(H)	Liner	Accommodate	Articles	X			
		Prevent	Leak		X		
		Provide	Insulation		X		
		Support	Insulation		X		
4(I)	Retainer	Apply	Force	X			
	Strip (Gasket)	Provide	Location		X		
1(J)	Gasket	Provide	Seal	X			
4(K)	Magnetic Strip	Provide	Force	X			
1(L)	Decorative Strip	Provide	Aesthetics	X			
–M	Insulating Glass	Prevent	Conduction		X		
	Wool	Provide	Insulation	X			

Table 2 Numerical Evaluation Chart for Function (Exp 11.2)

Part No.	1	2	3	4	5	6	7	8	9	10	11	12	13					
	Outer Pan	Ousset	Handle Rainforcement	Centre Stiffner	Lock Asay	Sleever Door Hinge	Handle	liner	Gasket Rat, Strip	Gasket	Magnetic Strip	Decorative Strip	Institution Glass Wool					
Basic Function	Provide Security	Provide Strength	Provide Location	Provide Softness	Provide Fastening	Provide Rotation	Facilitate Opening	Accommodate Articles	Provide Nutention	Provide Seal	Provide Force	Provide Aesthetics	Provide Institution	Weights	Adjusted Weights	Percentage Weights	percentage Cost	Value Index = Worth/Cost
A	B	C	D	E	F	G	H	I	J	K	L	M						
A	A2	A3	A3	A3	A2	A3	A3	A3	A3	A3	A3	A1	32	33	18.5	22.3	0.83	Poor Value and High Cost
B	B2	D1	B2	F2	B1	H1	B2	J1	B3	B1	M2	11	12	6.7	3.3	1.72		
C	D2	C1	F3	C1	H2	C1	J3	C2	L1	M2	4	5	2.1	4.8	0.44		Poor Value	
D	D2	F2	D2	H1	D3	J1	D3	D2	N3	15	16	5.9	1.2	7.42				
E	F3	G2	H2	E1	J3	E2	L1	M2	3	4	2.2	4.6	0.48				External Variable	
F	F3	F2	F2	F1	F3	F2	M2	23	24	13.4	1.9	7.05						
G	H2	G2	J2	G3	G1	M2	9	10	3.8	1.4	4.00							
H	H3	J1	H3	H2	M2	16	17	9.5	21.9	0.43							External Variable	
I	J3	I2	L2	L3	2	3	1.7	2.0	0.85								Poor Value	
J	J3	J2	M3	19	20	11.2	9.5	1.18										
K	L1	M2	32	1	0.5	6.5	0.08										Poor Value	
L	M3	5	6	3.4	3.0	1.13												
M	26	27	15.6	14	1.11													
Total	178																	

$$(1) \% \text{ weight (A)} = \frac{33}{178} \times 100 = 1.85$$

$$\% \text{ weight (B)} = \frac{12}{178} \times 100 = 6.7 \dots \text{etc}$$

(2) Cost to be calculated from the available price break-up of the component part of the Door-Assembly of the refrigerator.

$$(3) \text{ Value Index for A} = \frac{\text{Worth}}{\text{Cost}} = \frac{18.5}{22.3} = 0.83$$

$$\text{Value Index for B} = \frac{6.7}{3.9} = 1.72 \dots \text{and so on.}$$

(The greater, the better).

We conclude from Table 2 that while item A has poor value and high cost items C, 1 and K all have poor values.

Example 11.3: Table 3 shows a Function Cost matrix for a typical product (compass). It describes in two-words the function of a component. Its percentage importance (I) as obtained by paired comparison and percentage cost (C) obtained by allocating cost to attaining that function by that component. The Value index is given by I/C. A low value of I/C ratio shows a poor value area.

Table 3 (for example 11.3) Function-cost matrix for a compass

Sl. No.	Component	Function	% Importance I (%)	% Cost C (%)	Value Index I/C
1.	Pencil leg	Contain marker	16	25	0.6
2.	Pencil lock	Apply leverage	5	4	1.3
3.	Lock rivet	Create fulcrum	1	1	1.0
4.	Handle	Access Assembly	0	9	0.0
5.	Screw	Connect Components	12	7	1.7
6.	Nut	Induce Torque	7	3	2.3
7.	Washer	Maintain Friction	1	4	0.3
8.	Pinleg	Hold Pin	12	20	0.6
9.	Pin	Anchor Axis	21	4	5.3
10.	Pencil	Deposit Graphite	25	23	1.1

D) Creation Phase

The objective of this phase is to create ideas for value alternatives to accomplish the functions defined in the previous phase. The first step is to try answering the question 'What else will do?'. This phase requires creativity to be the focal point.

Brainstorming is a very effective way of promoting creativity. In brainstorming 'free wheeling' is permitted. Two powerful techniques to promote creativity are:

- a) **Establish positive thinking:** Here we divorce the judicial part of the mind from the creative part by insisting that we do not attempt to judge an idea simultaneously when it is being created.
- b) **Develop creative ideas:** This is done by cultivating uninhibited thinking and developing a multitude of ideas and approaches for accomplishing the defined functions. The desired thing at this point is a large number of ideas, no matter whether they look ridiculous. A number of check-lists and idea-stimulators could be used for the purpose.

E) Evaluation Phase

The objective of this phase is to select for further analysis the most promising of the ideas generated during the creative phase and to subject the ideas to a preliminary screening to identify those which satisfy the following criteria:

- Will it work?
- Is it less costly than the present design?
- Is it feasible to implement?

This phase of the Job Plan together with its supporting techniques must be undertaken with both care and diligence, for it is here that the judicial part of the mind is brought into active use. There are four techniques associated with this phase:

- a) **Refine and combine ideas:** The ideas must be practicable and to make them so we may have to refine an idea or combine two or more than two ideas.
- b) **Establish cost on all ideas:** As an idea or combination of ideas is being refined, an estimated cost should be calculated. What are the potential costs of implementing the idea and what are the resultant savings implied?
- c) **Develop function alternatives:** This makes further use of the information developed in the evaluation of functional relationships to mould the individual functional solutions into total solutions.
- d) **Evaluate by comparison:** When these rough total solutions and their related estimates of costs have been established they are compared to determine which one will provide the greatest value advantage.

The evaluation of value alternatives may have to be done on multiplicity of attributes-both tangible and intangible. The decision matrix approach can be a very effective way of multi-criteria evaluation. Here each criterion is assigned a relative importance and a normalised value score is allocated to each alternative on each attribute. The total weighted score is obtained for each alternative and the greatest score determines the preferred alternative.

Example 11.4: For the compass of Example 11.3 suppose the criteria for evaluation are: Ease of use, Ease of manufacturing, Safety, Quality and Attractiveness with the relative percentage weightage of 15, 30, 20, 25 and 10, respectively. Then the four value alternatives can be compared by using decision-matrix approach as shown in Table 4. As can be seen value alternative A_2 is the best as it gives the greatest total weighted score.

Table 4

Decision-Matrix to evaluate value alternatives for a compass

Sr. N o.	Value Alternat ive	ATTRIBUTES					Total Score
		Ease of use (15)	Ease of Manufat- curing (30)	Safety (20)	Quality (25)	Attract- iveness (10)	
1	A_1	100	30	50	70	100	61.50*
2	A_2	80	100	100	50	50	79.50**
3	A_3	30	50	70	100	70	61.50
4	A_4	50	60	80	50	60	57.00

* $(15 \times 100 + 30 \times 30 + 20 \times 50 + 25 \times 70 + 10 \times 100) / (15 + 30 + 20 + 25 + 10) = 61.50$

** A_2 is the best alternative, being the maximum scorer.

F) Investigation Phase

The three techniques of this phase further refine the selected ideas into workable and acceptable solutions providing lower cost methods for performing the desired function. The three techniques are:

- Use Company and Industrial Standards:** Within a standard lies tried and proven solution to a problem. We should try to use standards to the extent possible.
- Consult Vendors and Specialists:** The vendor may prove to be invaluable source of help in VE programme because he knows more about his product and its potential capabilities than most of his customers. We may decide to buy an item from the vendor instead of making it within if it is a cheaper and better proposal. Suppliers should be asked for cost-reducing and quality improving ideas. The degree of VE assistance by vendors also varies directly with the types of rewards, such as giving more business to cooperating vendors. Specialists can also contribute by suggesting a better material substitute, for example, by virtue of vast and

up-to-date knowledge they may have in their chosen area of specialisation. In VE philosophy the consultation with others is a strength rather than a sign of weakness.

- c) **Use Specialty Products, Processes and Procedures:** These in many cases provide lower-cost way of accomplishing the function; but before being adopted these should be evaluated to ensure lower costs in relation to standard products, processes and procedures

G) Recommendation Phase

This is the final phase of the Job Plan in which the finally selected value alternative is recommended for acceptance and implementation. It is vital in the sense that the entire project of conducting VE would succeed only if the recommendation is accepted. Many a time the acceptance of the suggested alternative depends upon the way it is presented to the management. The two techniques associated with this phase are:

- a) **Present Facts:** Facts usually speak for themselves.
- b) **Motivate Positive Action:** The presentation of accurate, specific and detailed facts and costs will motivate positive action. This technique requires the follow-up to make sure that the action is taken for idea implementation.

The presentation of facts can be either verbal or written in standard format or in combined form. The combined strategy is the best. The final recommendation need not contain all the data but should contain sufficient information to enable decision makers to find the course of action to be taken.

Example 11. 5: We take the same phase. After successfully carrying out VE Job Plan, the improved example as 'Door Assembly' of a refrigerator which was given for functional analysis design of the 'Door Assembly' was suggested. Figure II shows the existing design and the proposed design. By the proposed improved design of the door assembly of refrigerator by VE there would be a saving of considerable amount to the company manufacturing the unit in its factory per year. The new design will perform its role well without jeopardizing the functions to be accomplished by such as assembly.

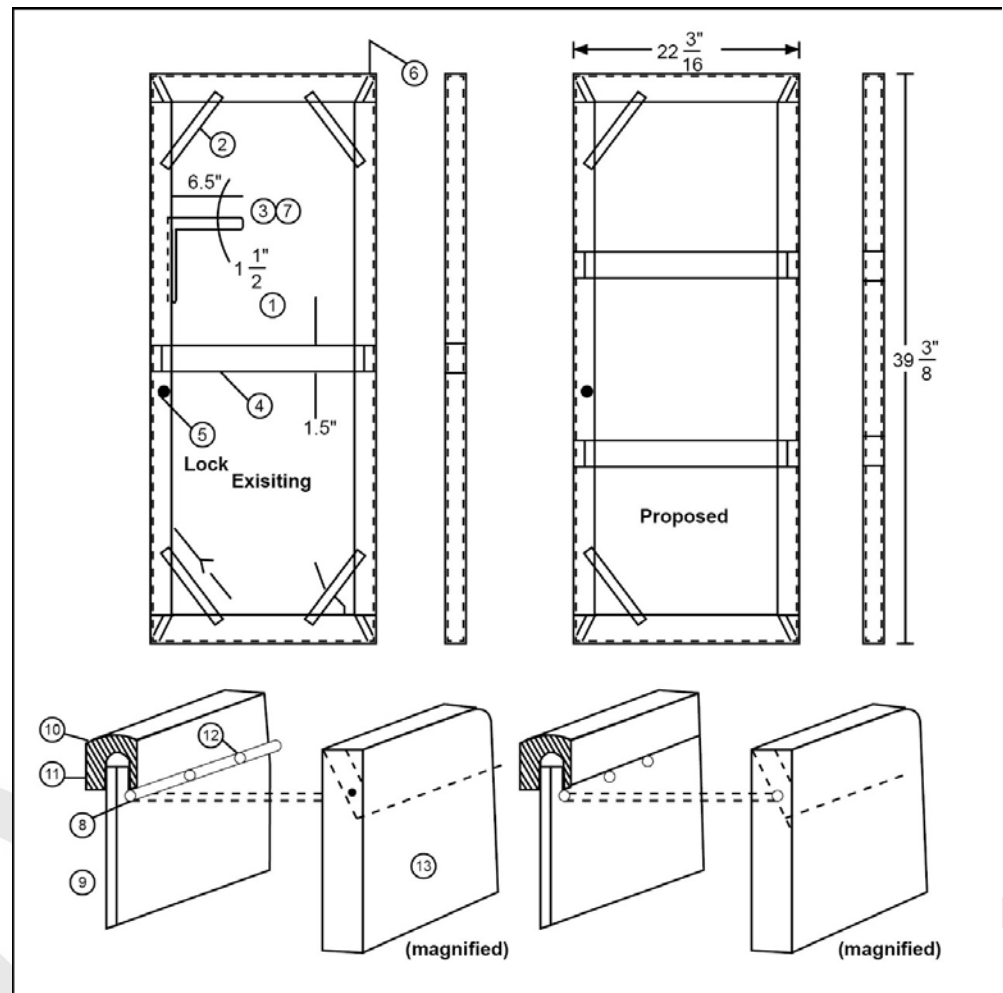


Figure II: Existing and Proposed Door Assembly.

Example 11.6: The fig III shows a typical part redesigned with manufacturing considerations. The revised design has much less number of parts and hence much reduced cost compared to the original design.

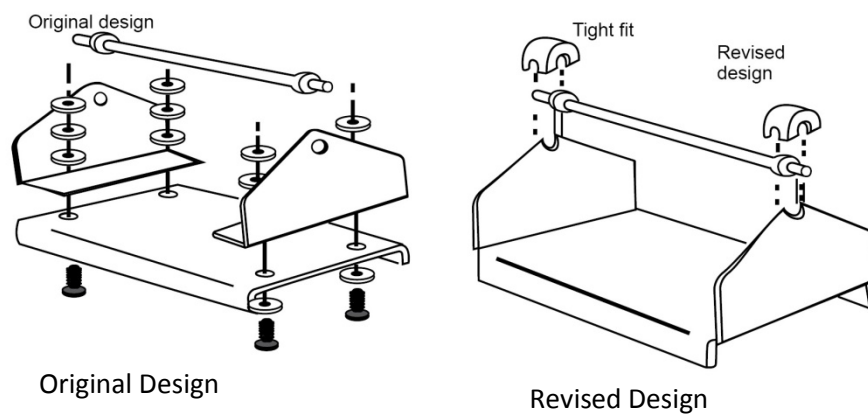


Figure III: Existing and Proposed Design of Portable Rack.

Other Variants of Job Plan

Some other variants of the Job Plan described above have also been reported. These are: DARSIRI method and FAST. The FAST is the most powerful of these and will be discussed in detail in the next section. DARSIRI is essentially similar to the Job Plan of Mudge described above. The seven steps involved are- D (Data Collection), A (Analysis), R (Record of Ideas), S (Speculation), I (Investigation), R (Recommendation) and I (Implementation).

These are self-explanatory steps and hence need not be elaborated.

11.5 FAST DIAGRAM AS VALUE ENGINEERING TOOL

This technique is developed by Charles. Bythaway and it is used to establish the relationship between functions in the analysis of an entire system, process or complicated assembly and gives a better understanding of interrelationships of function and their cost. FAST diagram is shown in fig IV.

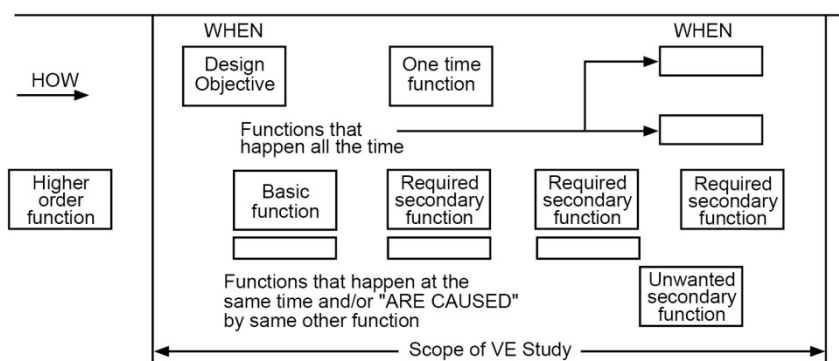


Fig IV- Function Analysis System Technique (FAST)

CONSTRUCTION OF A FAST DIAGRAM OF A BALL POINT PEN

The FAST diagram is represented in Fig. IV(a)

The first step is to identify all the functions of the parts.

The parts of the ball pen and functions of parts are shown in Table 5

Table 5

Part	Function	Remarks
Tip	Improves look, locate part	Chromium plating
Plastic neck	Hold part, provide grip, facilitate maintenance	Step in tip
Spring	Provide tension	—
Refill	Contain ink. control flow, restrict movement	—

Ink in refill	Make marks	—
Plastic barrel	Enclose part, identify company, air flow.	Hole in barrel, name on barrel.

Basic function—Provide impression or MAKE MARK

Secondary functions— Improve look

Provide grip

Control flow

To start with, MAKE MARK (basic function).

The question “why do we need this function is asked ?”

The answer is “to communicate ideas”. This function is shown on the left of the FAST diagram.

How do you make marks?

The answer is by performing the functions “contain ink and control flow” which represented right side of basic function.

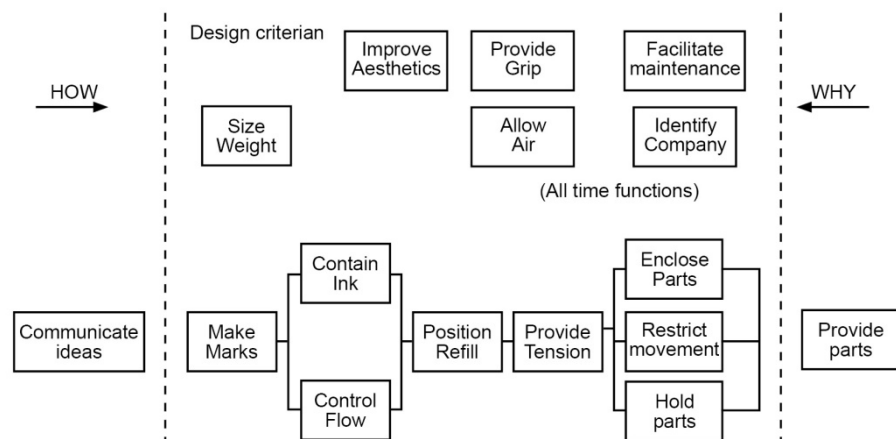


Figure IV (a) Function Analysis System Diagram for pen.

Next question is how do we control flow and contain Ink? Then the answer is to position refill, i.e., by making use of spring whose function is to provide tension, which is represented in the Fig. IV(a). Then the other functions are to be considered. The question ‘when do we improve look? All the time (ans). The all time functions are placed on the right hand top corner of the diagram. The other functions are represented as shown in order to determine the scope of the problem, the FAST diagram includes scope rules (Vertical broken lines). The left scope line is placed between the basic function under consideration (make marks) and highest order basic function (Communicate Ideas). The scope line on the right hand is determined by drawing a vertical broken line to the left of the function that is suitable input to the system "In this case, provide part is the suitable input." Design parameters, are placed

inside the scope lines. In the next phase, the generation of alternative ways of performing desired function is taken up. By observation of adjacent functions on the FAST diagram many new ideas may be found to combine. This leads to better performance of function.

11.6 SOME CASE STUDIES IN VALUE ENGINEERING

Value engineering has been very extensively applied in product design, systems and procedures and a very large number of case studies have been reported in books and journals on Value Engineering. In many of these case studies large amounts of savings have been reported. In Indian industries value engineering applications have been reported from TISCO, TELCO, Escorts, Hindustan Lever, Kelvinator, Railways, Godraj, BHEL, NTPC, L&T, Reymond, and a host of other public and private organizations. It is also known to have been applied in Indian Army, Navy and Air Force.

Some very simple case illustrations are as follows:

- i) **Problem:** Make design changes to reduce the construction cost in a large garage for a trucking firm.

Function: Protect Trucks

General Explanations and Solutions: Company management had drawn plans to construct a large garage complex for its fleet of trucks. The value Analysis pointed out that trucks were on road on an average of 20 out of 24 hours. What was really needed was a large parking area and a small maintenance building.

- ii) **Problem:** Reduce the number of guards by combining entrances to classified areas.

Function: Monitor doors

General Explanations and Solutions: It was difficult to reduce the number of doors to the classified areas. However, it was found that each guard could monitor and control two entrance doors by using CCTV and electric door locks.

- iii) **Problem:** Reduce the manufacturing cost of gasoline tanks for the landing aircrafts.

Function: Hold gasoline

General Explanations and Solutions: Initial design was inherently very costly. It was discovered that standard 55 gallon steel drums could be easily modified, coated and used.

- iv) **Problems:** Reduce the manufacturing cost of oil dipstick

Function: Measure Oil

General Explanations and Solutions: It was discovered that the standard dipstick used in large numbers could be more economically purchased from outside vendors instead of making.

11.7 BEHAVIOURAL AND ORGANISATIONAL ASPECTS OF VALUE ENGINEERING

Basic foundation of VE is structured around the effective use of people in teams. If team work is not properly harnessed it may not achieve major cost reductions. Some problems and roadblocks that are commonly encountered in the VE process are:

- i) Individuals involved in VE usually have other jobs and are already busy.
- ii) Teams may be inherently conservative, non-coherent and may avoid decisions and waste time.
- iii) Individual members of the team may have vested interests in resisting changes.

The success of VE study is enhanced if organisational and behavioural aspects are considered early in VE process. Hence the importance of the general phase of the VE Job Plan. Some important factors are;

- a) **Organising for VE:** Organising of VE function itself is very important. There are many alternative ways of doing it and there are many questions to be answered. Size, composition, level of participation and leadership are some of the relevant issues. VE may be organised as a team of multidisciplinary areas coordinated by a value engineer/industrial engineer. It may be an independent cell in staff level or it may be visualised as a philosophy-conditioning of mind so that every individual be trained to be value conscious. As a result it gets reflected in his decisions and attitudes towards problem solving. The right choice is contingent upon various situational parameters
- b) **Decision Making:** How are decisions to be made in a team? What are the external influences? What are the processes of approval? Are there some relevant issues that must be debated in the early stage of VE process?

11.8 BENEFITS OF VALUE ENGINEERING AND CONCLUDING REMARKS

Value Engineering helps in improving efficiency as well as effectiveness of products, systems and procedures. In general, VE,

- i) enables people to pinpoint areas that need attention and improvement.
- ii) provides a method of generating ideas and alternatives for possible solution to a problem.

- iii) provides a means of evaluating alternatives including intangible factors.
- iv) provides a vehicle for dialogue.
- v) documents the rationale behind decisions.
- vi) materially improves the value of goods and services.

In conclusion it must be re-emphasised that VE/VA is an extremely powerful methodology for cost reduction and value improvement and is becoming more and more popular. It is applicable to all areas: hardware, products, services, systems or procedures, and in all functional processes: purchasing, designing, producing, packaging, physical handling and distribution.

11.9 INTRODUCTION TO QUALITY ASSURANCE

You all must have come across the word **quality** in different contexts. All of us look for good quality in goods and services. We all realise the fact that the major achievement of industrial revolution has been the ability to mass produce a variety of goods of uniform quality, the classic example being the automobile. You will agree that the characteristic which sets apart Japanese goods as a superior or class, is precisely their quality.

In this unit we will describe the assessment, control and management of the quality function in an industrial organisation. We will develop a simple working definition of quality and then outline the assurance aspects of quality management.

Statistical techniques have contributed substantially to the success of modern quality control. Two of the important statistical techniques, viz., Acceptance Sampling and Control Charts will be developed in detail. Finally we will outline the role of computers in the area of quality control.

While this unit will outline methods and techniques which are useful in quality control and quality management, a successful quality improvement will depend on the skill and efficiency of the manager in using these techniques.

11.10 CONCEPT OF QUALITY

Even though we all talk of quality, it is not easily defined. Before we give a definition, it will be a good idea to give your own definition.

One of the accepted definitions of quality is **fitness for use**. An equally good definition is **conformance to requirements**. Note that in both the definitions quality is defined relative to use, rather than as a general characteristic that may be intangible. By this simple, yet practical definition, if a product or service lives up to expectations, it is of high quality. On the other hand, extra fine finish or using materials that are far stronger than required does NOT

add quality to an item unless it somehow causes the item to conform to its requirements better.

11.11 COST OF QUALITY

The term cost of quality is often a misnomer. Cost of quality is a measure of the cost to the firm for a lack of quality. It is very difficult to measure and often cannot be found in account books. One has to carefully back calculate, as most of the cost elements are hidden.

Quality costs are distributed throughout the organisation. Most organisations include only the cost of quality control departments whereas the cost of inspection, and measurement carried out in production departments are often ignored. More importantly the cost of bad workmanship, wastages and rework, etc. are often not included in quality costs. Careful examination of quality costs should account for Prevention, Assessment, Control Costs and costs due to lack of control.

"Quality is free, but it is not a gift". This statement sums up the opinion that effective, permanent quality improvement is difficult to achieve, but more than pays for itself in increased productivity.

11.12 QUALITY MANAGEMENT

Quality assessment is an investigation of the level of quality being achieved.

Quality control on the other hand, begins with assessment, and includes action taken to eliminate unacceptable quality. The typical quality control programme is based on periodic inspection, followed by feedback of the results and changes or adjustments whenever necessary. Quality assurance includes quality control, but it also refers to emphasis on quality in the design of products, processes and jobs and in personnel selection and training. **Total quality control** refers to the managerial commitment to quality so as to include the quality aspect in every functional area of work, production, marketing, finance and personnel. It also includes behavioural science based techniques like Quality Circles and Zero Defect Programmes. Naturally, the management of quality is an extensive area of study.

Quality assurance as an idea is quite old, but a systematic inclusion of quality assurance in organisations is a twentieth century phenomenon. Statistical methods of quality control were first proposed by Shewart in 1924, in the United States.

Intensive training courses in statistical control popularised by the American and Japanese industries contributed to much of the success of quality control programme. Recently the concept of **Quality Circles** has been a runaway success in Japanese industries. **A quality circle is a group of employees whose assignment is to identify problems, formulate solutions, and**

present their results to management with Suggestions for implementation. It is getting increasingly popular with employees and management in India also.

11.13 QUALITY ORGANISATION

A common mistake is to view quality as the responsibility of the department that produces the goods or services. Lack of conformance, however, can be a problem of design or even advertising. Consider the manufacture of automobile transmissions. If the gears are improperly designed, the transmission will fail despite the best quality of the manufactured gears. **That Quality is Everyone's Business** must be understood by everyone in the organisation.

Also, quality begins at the product concept stage and extends throughout the development, production, delivery and use of an item. Causes of poor quality can occur anywhere in the organisation, from top management to the shop floor worker, in accounting, production, sales, service or any other functional area of management (including the quality control function itself!). Some quality problems have roots outside the organisation, such as defective supplies from a vendor or incorrect specifications from a customer.

To achieve success, a major commitment to quality must be made by top management, and it must be visible to all the employees. Major quality problems often cross departmental lines, so barriers to system-wise actions must be removed. Quality improvement must be established as a positive effort rather than blaming the assignment. In general, training is the key to the success of quality control. Keeping these principles in mind, several alternatives exist for organising the quality control function.

11.14 ACCEPTANCE SAMPLING

One of the powerful statistical techniques of quality control is Acceptance Sampling. This technique is generally used in those situations where items are inspected in batches, generally known as lots. For example, you may receive a shipment of 10,000 electric bulbs and you may have to decide whether to accept the shipment or return it back to the supplier. The acceptability will depend on the acceptable quality of the lot, which in turn depends on the use and the price you are willing to pay for this quality. Suppose you decide to accept if the average fraction defective is less than 5 per cent. Then to ascertain the actual quality you may decide to inspect each and every bulb. Such a strategy of **100 per cent inspection**, however, may often be expensive and impractical. In such cases a more intelligent way is to use the concept of **Sampling Inspection**.

The idea of sampling inspection is to inspect only a small portion of the lot and **infer** the quality of the lot, based on the quality of the sample. Acceptance is based on the inference made from the sample and hence the

technique is known as **Acceptance Sampling**. Typically a lot is specified by its size (N) and the fraction (f) of defectives that are expected to be present (at the most) in the lot. The principles of statistics are used in the inference process.

Interestingly the concept of acceptance sampling is no different from the strategy adopted by a typical housewife who decides whether or not a pot-ful of rice is cooked by inspecting just a spoonful of grains.

Two things must be kept in mind. In order that sampling inspection might work, the sample must be **representative** of the lot. Typically this is ensured by choosing the sample at random so that every portion of the lot has equal representation in the sample. Such a sampling is known as **Random Sampling**. Second, a sample is only representative and not identical (in characteristic) with the lot. In the inference process, therefore, a few good lots may be rejected and a few bad lots may be accepted. We can control such **sampling errors**, but they cannot be eliminated. In fact in the design of **sampling plans** we will ensure that the errors are kept below certain acceptable levels.

Sampling Plans

We will first consider a **single sampling plan** in which accept/reject decisions are based on the results of a single sample of n items from the lot of N items. Each of the n sample items is inspected and categorised as either **acceptable** or **defective**. Such a plan is known as **Sampling by Attributes** (we will not discuss **Sampling by Variables** in this unit. The interested reader may refer to the references cited at the end). If the number of defective items in the sample exceeds a pre-specified cut off level, c , acceptance number is c the entire batch is rejected. (Depending on costs, a rejected lot may be scrapped or 100 per cent inspected or returned back to the manufacturer). Since a finding of c or fewer defective items in the sample implies accepting the batch, c is often referred to as the **acceptance level**. A Sampling Plan is specified by the values of n and c . (c =acceptance number)

The sampling plan is supposed to separate good lots from bad ones. As mentioned earlier there are bound to be sampling errors. We will now study the probabilities of such error graphically, using an **Operating Characteristic Curve**.

The Operating Characteristic Curve

It is useful to have a simple picture that allows us to compare sampling plans as to how they will react to different lots with **unknown, varying** fraction defective. Such a comparison is provided by the, **operating characteristic curve (OCC) which displays the probability of accepting a lot with any fraction defective**.

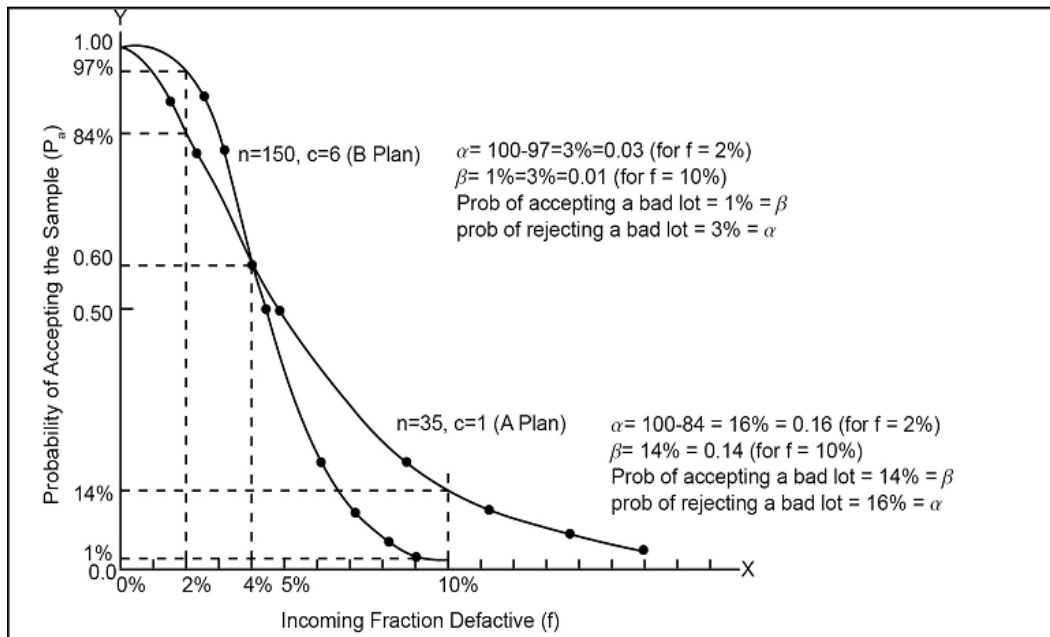


Fig v. operating characteristic curve.

Figure V shows OCC for two single sampling plans A and B with $n = 35$, $c = 1$ and $n = 150$, $c = 6$, respectively. For example, suppose that a lot with $f = 10$ per cent defectives is considered to be a bad lot and a lot with $f = 2$ per cent defectives is considered to be a good lot. From Figure V, it is clear that sampling plan A would stand a 14 per cent chance of accepting a bad lot. The same unfortunate error can occur with the sampling plan B, with larger sample size also, but the probability of error is much smaller. In fact it is only 1 per cent. The sampling plan B is also better at not rejecting good lots ($f = 2$ per cent). Sampling plan A has 16 per cent chance of rejecting a good lot whereas sampling plan B has only 3 per cent chance of rejecting a good lot.

It is not surprising that **a larger sample does a better job of discriminating between good and bad lots**. It has more information. However, the price for increased accuracy is higher inspection costs. The design of a sampling plan has to optimally trade-off cost with discrimination.

The values of the ordinates of the Operating Characteristic Curve are determined from the Poisson Distribution. The actual details can be found in the advanced texts listed in the reference.

Design of Single Sampling Plan

You have to design a sampling plan (n, c) that has an OCC that meets certain pre-specified requirements. Generally the design is based on the following criteria that are related to the probability of making either of the following errors: accepting a bad lot β and rejecting a good lot α . The criteria are established subjectively and ultimately should reflect the cost of accepting a bad lot or rejecting a good lot.

Needless to say before α and β values can be specified, one has to decide what is a good lot and what is a bad lot. Invariably this is done by specifying the lower/upper limits of fraction defective (f), as illustrated below:

AQL (Acceptable Quality Level) the fraction defective (f) that the user considers acceptable. Thus if a batch were known to have a fraction defective equal to AQL, it should not be rejected.

LTPD (Lot Tolerance Per cent Defective) the fraction defective that defines a bad lot or one that should be rejected. Of course AQL must be less than LTPD.

Producers Risk (α) the largest allowable probability of rejecting a good lot (due to statistical error). Note that a good lot has fraction defective less than or equal to AQL (generally 5 per cent).

Consumers Risk (β) the largest allowable probability of accepting a bad lot (due to statistical error). Note that a bad lot has fraction defective greater than or equal to LTPD (generally 10 per cent).

Example 11.7

Consider a manufacturing situation with the following values:

$$\text{AQL} = 0.02, \quad \alpha = 0.05$$

$$\text{LTPD} = 0.10, \quad \beta = 0.01$$

Design a suitable sampling plan.

Solution. To design the sampling plan, follow the instruction at the bottom of the chart Table 6 (Here the notation μ is the same as our notation m = mean value). Note that we have to read off $\beta = 0.01$ and $(1 - \beta) = 0.99$ rows only. First find a c value for which $\mu_\beta / \mu_\alpha < 0.10/0.02 = 5$ (= LTPD/AQL) Starting With $c = 0$ we read off $\mu_\beta = 4.6052$ and $\mu_\alpha = 0.0513$

But $\frac{4.6052}{0.0513} = 89.796$ does not satisfy $\frac{\mu_\beta}{\mu_\alpha} \leq 5$.

Continuing with $c = 1, 2, 3, 4, 5$ etc. we find that for

$$c = 6, \frac{\mu_\alpha}{\mu_\beta} = \frac{14.5706}{3.2853} = 4.4350 < 5 (\text{satisfied}).$$

Hence we choose $c = 6$. To get the value of n , the limits are $n_\beta = \frac{\mu_\beta}{\text{LTPD}}$

$$\text{and } n_\alpha = \frac{\mu_\alpha}{\text{AQL}}, \therefore n_\beta = \frac{14.5706}{0.10} = 146 \text{ and } n_\alpha = \frac{3.2853}{0.02} = 165$$

Hence sampling plans with size in the range of 146 to 165 will satisfy the requirement. The exact value of α and β for any sampling plan can be determined using **Thorndike chart** again.

Table 6
Thorndike Chart for Single Sampling Plans

		Acceptance Number C											
		0	1	2	3	4	5	6	7	8	9	10	
Acceptance Probability	P_a	$\mu = nf = \text{expected number defective in the sample}$											
Rows, entries denoted μ_β	0.010	4.6052	6.6383	8.4059	10.0450	11.6046	13.1085	14.5706	16.0000	17.4027	18.7831	20.1447	
	0.025	3.6889	5.5716	7.2247	8.7672	10.2416	11.6683	13.0595	14.4227	15.7632	17.0848	18.3904	
	0.050	2.9957	4.7439	6.2958	7.7537	9.1535	10.5130	11.8424	13.1481	14.4346	15.7052	16.9622	
	0.100	2.3026	3.8897	5.3223	6.6808	7.9936	9.2747	10.5321	11.7709	12.9947	14.2060	15.4066	
	0.200	1.6094	2.9943	4.2790	5.5150	6.7210	7.9060	9.0754	10.2325	11.3798	12.5188	13.6507	
(1- α) rows, entries denoted μ_α	0.500	0.6931	1.6783	2.6741	3.6721	4.6709	5.6702	6.6696	7.6692	8.6690	9.6687	10.6685	
	0.800	0.2231	0.8244	1.5350	2.2968	3.0895	3.9037	4.7337	5.5761	6.4285	7.2892	8.1570	
	0.900	0.1054	0.5318	1.1021	1.7448	2.4326	3.1519	3.8948	4.6561	5.4325	6.2213	7.0208	
	0.950	0.0513	0.3554	0.8177	1.3663	1.9701	2.6130	3.2853	3.9808	4.6952	5.4254	6.1690	
	0.975	0.0253	0.2422	0.6187	1.0899	1.6235	2.2019	2.8144	3.4538	4.1154	4.7954	5.4912	
	0.990	0.0101	0.1486	0.4360	0.8233	1.2791	1.7853	2.3302	2.9061	3.5075	4.1302	4.7712	

- 1) To plot an OC curve for a given sample plan (n, c): (a) Find the column for your c value. (b) Divide each number in that column by n . The results are the f values for the horizontal axis. (c) The P_a values for the vertical axis, are in the far left column.
- 2) To find a single sampling plan :
(a) Find c for which $\mu_\beta / \mu_\alpha \leq \text{LTPD/AQL}$.
(b) Then choose any n between $\mu_\beta = \mu_\beta / \text{LTPD}$ and $\mu_\alpha / \mu_\alpha / \text{AQL}$
- 3) To find the acceptance probability for a given n, c and f : (i) Multiply (n) (f). (ii) In the appropriate c column, find values above and below nf . (iii) In the P_a column read upper and lower limits for P_a in two rows from step (ii) (interpolate, if required).

Average Outgoing Quality

The inspection process rejects lots with high fraction defectives. After rejection either you may stop, or you may continue the inspection of all the items in the rejected lot and all defective items are replaced with good items. Such a policy is known as **Rectifying Inspection**.

In rectifying inspection, all outgoing lots consists of N items either accepted ones or rejected ones. Suppose a lot has incoming fraction defective f . If it is accepted ($N - n$) items remain uninspected. We, therefore, expect $f(N - n)$ defectives in the accepted lots (assuming that the defectives found in the sample are replaced with good ones). In contrast, if it is rejected and hence (100 per cent rectified and inspected) there are no defectives. Thus if P_a is the probability that the sampling plan will accept the lot,

$$\begin{aligned}\text{Outgoing fraction defective} &= \frac{(P_a)(f)(N - n) + (1 - P_a)(0)}{N} \\ &= (P_a)(f) \left(\frac{N - n}{N} \right) \simeq (P_a)(f)\end{aligned}$$

A plot of outgoing fraction defective against incoming fraction defective (f) is generally called the **Average Outgoing Quality (AOQ)** curve. Figure VI shows the curve for sampling plan B ($n = 150$, $c = 6$) of the earlier example. This curve has a surprising property that, as f increases, there comes a point at which the outgoing fraction defective actually begins to improve. The reason being that the sampling plan rejects most bad lots and they are rectified through 100 per cent inspection.

The most critical incoming fraction defective f gives the worst outgoing quality. On the average, the value of that critical f is not important but the corresponding outgoing fraction defective generally known as average outgoing quality limit (AOQL) is extremely useful. No matter what the incoming fraction defective is, the long-run average outgoing fraction defective will not be worse than AOQL.

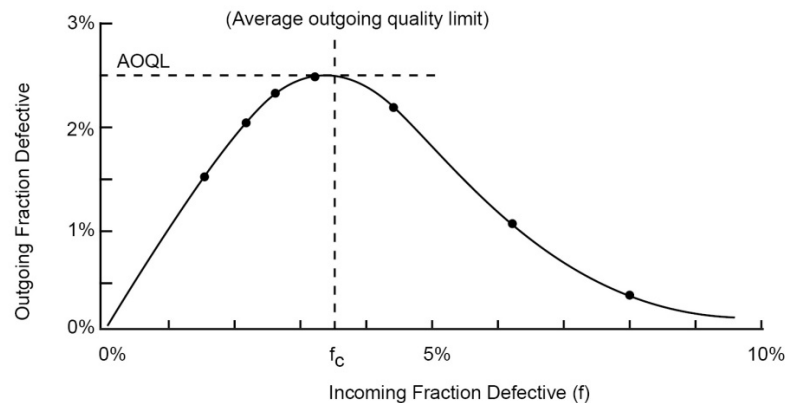


Fig VI. AOQ for sampling plan B ($n=150$, $c = 6$, $N=10,000$)

Table 7 AOQL Factor

Acceptance Number (C)	AOQL factor (Y)
0	0.3679
1	0.8400
2	1.3711
3	1.9424
4	2.5435
5	3.1682
6	3.8120
7	4.4720
8	5.1457
9	5.8314
10	6.5277

You do not determine AOQL by plotting the AOQ. One can use the given AOQL factor table. To get the AOQL simply use the formula

$$\text{AOQL} = \text{AOQL factor} \left(\frac{1}{n} - \frac{1}{N} \right)$$

Many managers prefer to use the AOQL as a criterion for designing a sampling plan rather than trying to decide on values of AQL, LTPD, α and β . Dodge and Romig (1959) present tables that are designed for this purpose. In fact these tables meet the requirement of a specified AOQL and minimise the expected number of items inspected per lot.

The OCC approach and AOQL based approach are but two of the many other approaches that can be used to design a sampling plan. Choice among them is a match of personal experience, the exact situation and the objectives of the organisation. Regardless of the approach, all sampling plans have both an OC curve and an AOQ curve, so the principles discussed in this unit can be used to evaluate any sampling plan.

Double and Multiple Sampling

Extensions of the single sampling plans to double and multiple sampling plans are also available. In a double sampling plan; after the first n_1 samples have been inspected there are three choices depending on the number of defectives found:

- 1) reject the lot
- 2) accept the lot, and
- 3) draw a second sample of n_2 items.

If choice (3) is made the final accept/reject decision is made on combined sample of $n_1 + n_2$ items. A multiple sampling plan operates in the same way, but with more than two samples. Double and multiple sampling plans reduce inspection costs because many accept/reject decisions are made based on the first sample which is smaller than that of the single sampling plan. However, single sampling plan is more common and easy to use. Details of multiple sampling plan are found in references.

11.5 PROCESS CONTROL

Variability

All products and services have a certain amount of natural variability because of variations in the input as well as imperfections in the process. For example, different quality of raw materials could have been used and different quantities of chemicals could have been used in the process. This

process variability may be measured by the process standard deviation σ ,

which indicates how much the products will vary even if the process is in control.

Products have to meet **specified tolerances** imposed by their intended use. Accordingly the natural variability must be substantially smaller than the specified tolerance. This is explained in Figure VII in which the central line is the desired average of the process and the dashed lines are the '3-Sigma limits' representing the natural process variability.

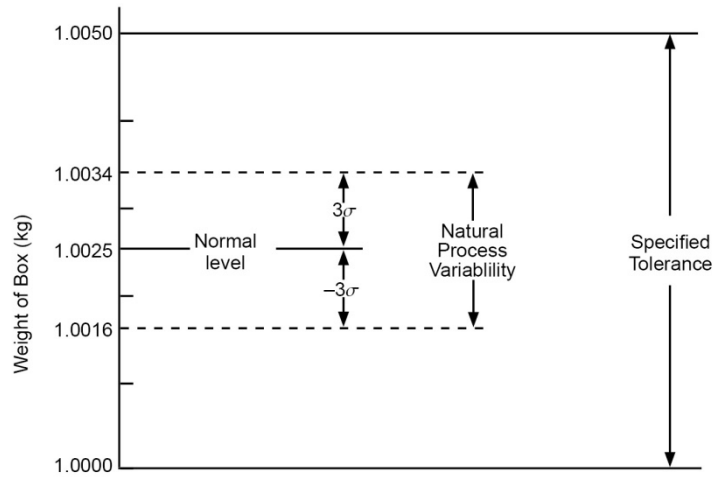


Fig VII Process Variability

It can be shown that variations of more than 3σ from the process average are very unlikely. In fact it is about 0.25 per cent if the process follows the normal distribution and definitely less than 5% for most processes. The solid lines represent the tolerances specified by the intended use of the product.

Within the specified tolerances, a certain amount of process variability is to be expected. However, It is the goal of the **statistical process control** to determine when the process variability is getting out of hand, so that corrective action can be taken, preferably before the required tolerances are violated. This is generally achieved by a **Control Chart**

Control Chart

In order to provide rapid feedback to an ongoing production process, methods somewhat different from acceptance sampling are appropriate. Samples are taken as soon as they are available, rather than waiting for the completion of a lot. This affords the opportunity to detect unplanned changes in the process, shortly after they occur and take a quick action, such as adjusting the machine.

The most common device used for this purpose is Shewart Control Chart introduced in 1931. **The control chart is a visual display of the result of an inspection process incorporating carefully derived limits to indicate unusual behaviour.** A control chart can be based on categorical information or actual measurement. Accordingly, they are called **control chart for**

variables (controlling quality through measurement) and control chart for attributes (controlling quality through counting). Since control chart for variables are more commonly used and more powerful, we will describe them first.

The control chart is based on the idea that the average of a sample of several items will tend to cancel out the normal process variability, so that undesirable changes in the process will be more visible. We will illustrate the idea through an example.

$\bar{X}$ and R chart(control charts for variables)

This chart is used for quality characteristics which are specified as variable, i.e., on the basis of actual measurement readings taken. The purpose or objectives of this chart are:

- To establish whether the process is in statistical control or not.
- To determine whether the process capability is compatible with the specifications
- To detect trends in the process so as to assist in planning, adjustment and resetting of the process.
- To show when the process is likely to be out of control. A number of samples of component coming out of the process are taken over a period of time. Each sample must be taken at random and the size of sample is generally kept 5 but 10 to 15 units can be taken for sensitive control charts. For each sample the average value $\bar{x}$ of all the measurements and the range R are calculated. The grand average $\bar{\bar{X}}$ is equal to the average value of all the averages $\bar{X}$ and $\bar{R}$ ($\bar{R}$ is equal to average of all the ranges) are found and from these we can calculate the control limits for the $\bar{X}$ and R charts. Therefore, For $\bar{X}$ charts:

$$\text{Upper Control Limit } UCL_{\bar{X}} = \bar{\bar{X}} + A_2 \bar{R}$$

$$\text{Lower Control Limit, } LCL_{\bar{X}} = \bar{\bar{X}} - A_2 \bar{R}$$

$\bar{\bar{X}}$ and $\bar{R}$ are also called centre line values. For R chart:

$$UCL_{\bar{R}} = D_4 \bar{R}$$

$$LCL_{\bar{R}} = D_3 \bar{R}$$

Here, the factors A_2, D_4 and D_3 known as the statistical factors depend on the number of units per sample. Larger the number, the closer the limits. The value of the factors A_2, D_4 and D_3 can be obtained from Statistical Quality Control tables. However, for ready reference these are given below in tabular form in Table 8. As long as $\bar{x}$ and R limits values for each sample are within the control limits the process is said to be in statistical control.

**Table 8: Statistical factors for computing control lines and control limits
for $\bar{X}$, R and s charts**

No. of Units in a sample	A ₂	D ₁	D ₂	D ₃	D ₄	d ₂ *
2	1.88	0	3.687	0	3.27	1.13
3	1.02	0	4.358	0	2.57	1.69
4	0.73	0	4.698	0	2.28	2.06
5	0.58	0	4.918	0	2.11	2.33
6	0.48	0	5.078	0	2.00	2.53
7	0.42	0.205	5.203	0.08	1.92	2.70
8	0.37	0.387	5.307	0.14	1.86	2.85
9	0.33	0.546	5.394	0.18	1.82	2.97
10	0.31	0.687	5.469	0.22	1.78	3.08
11	0.29	0.812	5.534	0.26	1.74	3.17
12	0.27	0.924	5.592	0.28	1.72	3.26
13	0.25	1.026	5.646	0.31	1.69	3.34
14	0.24	1.121	5.693	0.33	1.67	3.41
15	0.22	1.207	5.737	0.35	1.65	3.47

$$\text{*Process Capability} = 6\bar{\sigma} = \frac{6\bar{R}}{d_2}$$

The various reasons for the process being out of control may be:

(i) faulty tools (ii) sudden significant change in properties of new materials in a new consignment (iii) breakdown of lubrication system (iv) faults in timing of speed, mechanism etc. Tracking of these causes is sometimes simple and straight forward but when the process is subject to the combined effect of many factors, then it may be a lengthy and complicated business.

Example 14. The following record taken for a sample of 5 pieces from a process each hour for a period of 24 hour.

S.No.	Time	Measurements $\times 1/1000$					$\bar{X}$	R
1.	8 a.m.	995	997	1002	995	1000	0.998	0.007
2	9 a.m.	990	1002	997	1003	1005	0.999	0.015
3.	10 a.m.	1003	1005	998	1004	995	1.001	0.005
4.	11 a.m.	1002	999	1003	995	1001	1.000	0.006
5.	12 a.m.	1001	996	999	1006	1001	1.000	0.010
6.	1 p.m.	1004	1001	998	1004	997	1.000	0.007
7.	2 p.m.	1003	1002	999	1003	1004	1.002	0.006
8.	3 p.m.	1001	1007	1006	999	998	1.002	0.009
9.	4 p.m.	999	995	994	991	996	0.995	0.008
10.	5 p.m.	994	993	991	993	996	0.993	0.005
11.	6 p.m.	994	996	995	994	991	0.994	0.005

12.	7 p.m.	994	995	998	999	1001	0.097	0.007
13.	8 p.m.	1002	1004	1000	994	1000	1.000	0.010
14.	9 p.m.	1003	1000	996	1000	1005	1.000	0.009
15.	10 p.m.	996	1001	1006	1001	1008	1.103	0.012
16.	11 p.m.	995	1003	1014	1006	1008	1.003	0.012
17.	12 p.m.	1096	1005	1006	1009	1008	1.006	0.004
18.	1 a.m.	996	999	1001	1008	996	0.999	0.012
19.	2 a.m.	1001	1004	995	1001	1008	1.002	0.013
20.	3 a.m.	1003	995	1002	991	996	0.999	0.012
21.	4 a.m.	1004	991	993	997	1008	0.997	0.013
22.	5 a.m.	1003	997	998	1000	1001	0.999	0.006
23.	6 a.m.	1006	1001	999	996	997	0.999	0.010
24.	7 a.m.	1005	1000	1001	998	1000	1.001	0.007
Total							23.976	0.216
Average							0.999	0.009

Design control limits, make plot, draw inferences regarding quality.

Solution

$\bar{\bar{X}} = 0.99$ and $\bar{R} = 0.009$ from table 8 for a sample size of 5, we have $A_2 = 0.58$, $D_4 = 2.11$, $D_3 = 0$, then $UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R} = 1.004$, $LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R} = 0.994$
 $UCL_R = D_4\bar{R} = 0.019$ and $LCL_R = D_3\bar{R} = 0$

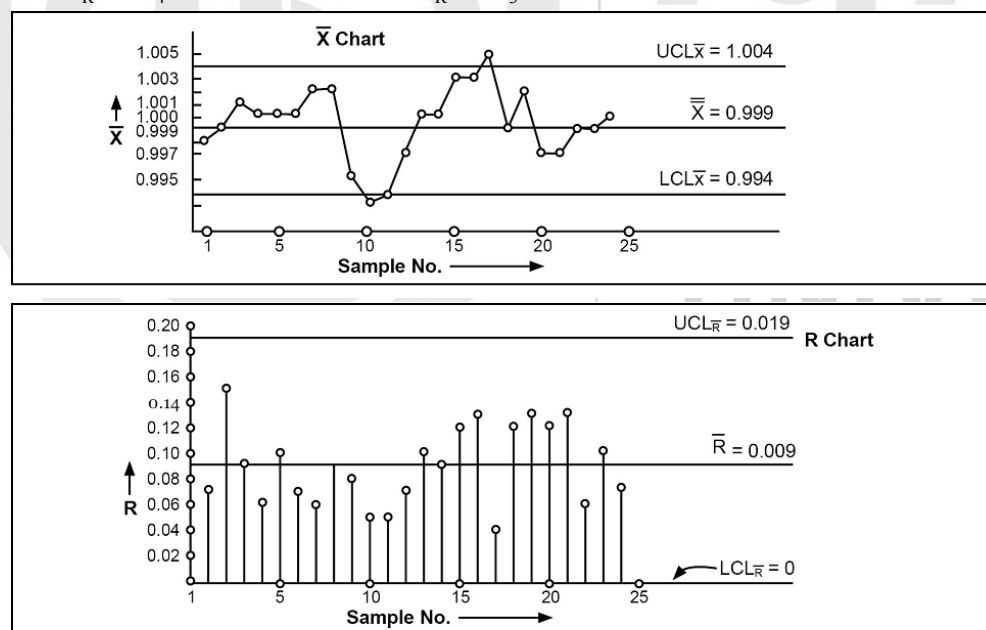


Figure. VIII

Now $\bar{X}$ and R charts are plotted on the graph as shown in Fig. VIII taking abscissa as sample number and ordinates as $\bar{X}$ and R respectively.

Inference. Let us look at the Fig. VIII. In the $\bar{X}$ chart, most of the time the plotted points representing average are well within the control limits but in Samples 10 and 17, the plotted points fall outside the control limits.

It means something has probably gone wrong here with the process and a check is needed to prevent the appearance of defective products (rectifying inspection).

If the causes have been eliminated, the sample nos. 10 and 17 will stay well within the control limits, but if more points fall outside the control limits then a thorough investigation should be made, even if it is necessary to shut down production temporarily until every thing is adjusted again and no more points fall outside.

Control chart $\bar{x}$ and R charts with $\sigma_{\bar{x}} = \sigma/\sqrt{n}$ (for variables)

Consider XYZ Company that uses an automatic machine to fill 1kg. boxes of sugar. The tolerances are specified as 1.000 kg. on the lower side (legal requirement) and 1.005 kg. on the high side (no point,wasting sugar). Since the spread is only 0.005 they selected a machine that has a natural process variability of $= 0.0003$. The three sigma limits of the machine therefore are $3(.0003) = .0009$ kg. above and below the mean. The spread is .0018 which is narrower than the specified tolerance of .005. They adjust the machine to fill boxes with an average 1.0025 kg. half way between the tolerance limits.

An $\bar{x}$ Chart (Average Control Chart) was set-up to detect when the machine goes out of control. In order to reduce the natural process variability, samples of $n = 5$ boxes were weighed, and the average weight per box, $\bar{X}$, was recorded for each sample.

Figure IX shows the control chart used for this machine and the four points plotted on the chart represent the values from four samples (a total of twenty 1 kg. boxes). We shall examine the details of the chart. There is an apparent trend in $\bar{X}$. The sample seem to be getting progressively heavier. However, despite the appearances, the trend in fig. IX, it may be due to random fluctuations. It is for this reason that we must incorporate the concept of **statistical significance** in our discussion. The standard deviation of the sample average is expressed through the formula $\sigma_{\bar{x}} = \sigma/\sqrt{n}$

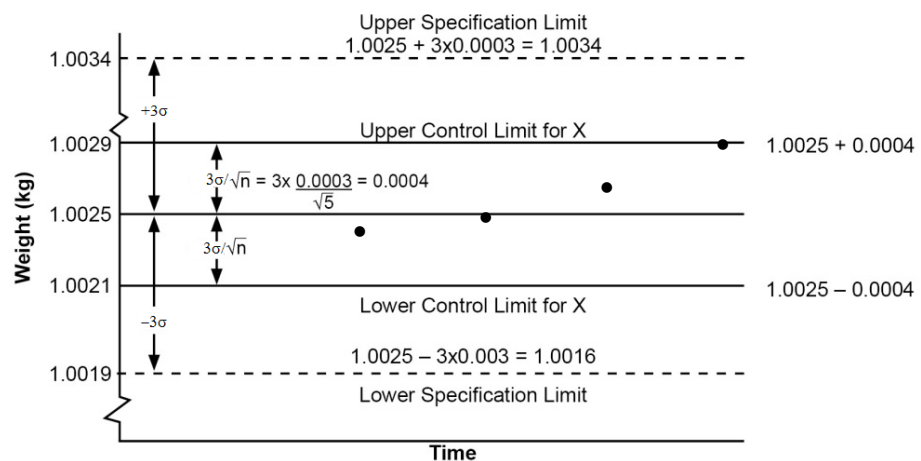


Fig. IX- $\bar{x}$ chart

Therefore, the averages of $n = 5$ boxes of sugar should have a standard deviation of $= 0.0003/\sqrt{5} = 0.000134$ kg. The control limits represent 3 sigma limits and are therefore (3) $(0.000134) = 0.0004$ above and below the intended average of **1.0025**. If a sample average falls outside these control limits the deviation from the process average is **statistically significant**.

The fourth sample falls is on the control limit and therefore there is a strong statistical evidence that more sugar is put into the boxes than what was intended and the machine needs adjustment. The R Chart (Range Control Chart) is also used to control the processes. The range of a sample is the largest value minus the smallest. An R chart is appropriate if process sometimes goes out of control in such a way that there is inconsistency in the values, but no shift in the mean value of the process. For example, a worker who is basically good might produce an inconsistent set of sizes (of some manufactured product) when he is fatigued. The R chart used to plot the data of XYZ Company appears in Figure X. (R is given to be $= 0.0007$)

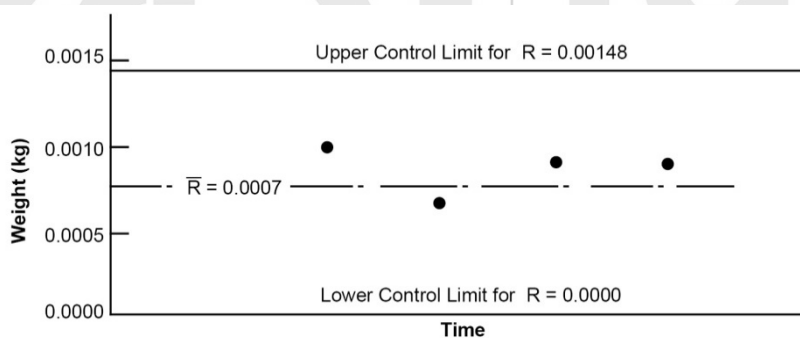


Fig X-R chart

The control limits for R chart are determined differently. There is no need for lower control limit which is generally (for $n \leq 6$ it is zero) zero. Table 9 an extract from the Table 8 (Factors for computing central lines and control limits) is used to set the upper control limit for an R chart and factor D_2 from the table is multiplied by the ' process standard deviation, σ . In the case of XYZ Company data, $D_2=4.918$ (for a sample size of 5) and hence upper control limit $=(0.0003) (4.918)=0.00148$. As can be seen in Figure X no statistically significant shifts are present.

Table 9: R chart Factor(extract from Table 8)

Sample size	D_3	D_2
2	0	3.686
3	0	4.358
4	0	4.698

5	0	4.918
6	0	5.078
7	0.205	5.203
8	0.387	5.307
9	0.546	5.394
10	0.687	5.469

Other Control Charts

There are several other control charts, including the p-chart which is used to control the process when the measurement is by attributes. In other words the decision is only to decide whether or not the sample item is acceptable. No measurement is taken. For example in using the GO/NO GO gauges one gets only such a measurement.

p-chart: The p-chart is based on the fraction defective, p , in a sample of n items. If p_0 represents the normal process defective (i.e. when the process is in control) then the 3 sigma control limits are,

$$p_0 \pm 3 \sqrt{\frac{p_0(1-p_0)}{n}}$$

This is based on the fact that the number of defectives has the binomial probability. The control chart is used just like an $\bar{X}$ chart, except that the fraction defective p is calculated rather than $\bar{X}$ for each sample of n items and a lower control limit is often omitted.

This is based on the fact that the number of defectives has the binomial probability. The control chart is used just like an $\bar{X}$ chart, except that the fraction defective p is calculated for each sample of n items and a lower control limit is often omitted.

Sample sizes are typically larger for p-charts than for $\bar{X}$ -charts. Since the information content of a yes/no measurement is much smaller than the actual variable measurement, the required sample size can be computed approximately from the following formula.

$$n = \left[\frac{1.645\sqrt{p_1(1-p_1)} + 3\sqrt{p_0(1-p_0)}}{p_1 - p_0} \right]^2$$

In this formula p_0 is the normal process fraction defective, p_1 is the specified fraction defective that is unacceptable. (p_0 like AQL and p_1 is like LTPD in acceptance sampling).

For example, consider ABC Company that makes ready-made shirts. It has been found that 4 per cent of the shirts are defective when the process is under control. ABC Company wants to be able to detect a shirt to 12 per cent defective on the basis of one sample of n items. Here $p_0=0.04, p_1=0.12$

therefore $n=197$ from the above formula. Hence the upper control limit is equal to

$$p_0 + 3\sqrt{\frac{p_0(1-p_0)}{n}} = 0.04 + 3\sqrt{\frac{0.04(1-0.04)}{197}} = 0.04 + 0.0419 = 0.0819$$

i.e 8.19%

c-Chart: c-chart is used in situations wherein opportunities for a defect in each production unit or a complaint from a customer are very large while the probability of their occurrence per unit tends to be very small or constant. The outcome of such a sampling process can be described by a Poisson distribution, Here the average number of defects is equal to:

$$\bar{c} = \frac{\text{total number of defects found in all sample}}{\text{total number of samples inspected.}}$$

$$\text{and } UCL_{\bar{c}} = \bar{c} + 3\sqrt{\bar{c}} \text{ and } LCL_{\bar{c}} = \bar{c} - 3\sqrt{\bar{c}}$$

11.16 USE OF COMPUTERS IN QUALITY CONTROL

Now-a-days with most of the computers including personal computers well written quality control packages are available. In some special cases these computers can be linked directly to take the sample measurements and control the process on-line.

These packages are likely to take much of the chores associated with the lengthy calculations and make the application of quality control techniques far more easy and yet effective.

11.17 SUMMARY

Value Engineering/Value Analysis is a systematic and organised effort to identify the functions of a product, system or procedure and to attain that function with minimum cost without jeopardising quality, aesthetics and appearance etc. The Systematic procedure is known as VE Job Plan. Its phases include General Information, Function, Creation, Evaluation, Investigation and Recommendation. Each phase has a set techniques associated with it. FAST diagram is another powerful technique for VE. Other important techniques are functional analysis, function-cost matrix, paired comparison and decision matrix. Value Engineering requires a good team spirit and an effective organisation. Benefits of VE in cost reduction and value improvement are tremendous. It is equally applicable to hardware and software projects.

Quality is fitness for use. Using this definition leads to many opportunities to improve both quality and productivity simultaneously. Many quality problems have causes that cross departmental boundaries. So a good quality

management system must make the entire organisation responsible for quality. Statistical methods are important tools for quality control. They separate random variations from real assignable causes of deviations from normal. Acceptance sampling helps in deciding the quality of a large batch (lot) from an inspection of small sample. The operating characteristic curve (OCC) precisely gives the risks associated with any sampling plan. The design of a sampling plan can be based on Operating Characteristic Curve as well as Average Outgoing Quality. Control charts display the results of inspecting a continuous process. This provides convenient and rapid feedback suggesting when feedback, overhaul or adjustment, may be needed. The design of control chart is based on sound statistical principle regarding the behaviour of sample mean.

The statistical methods described in this unit are used widely in manufacturing and service industry. They are also the basis for many of the commonly used, yet more complex, schemes described in the references.

11.18 KEY WORDS

Brainstorming: The process of generating creative ideas in a group by permitting free and uninhibited discussions among the team members.

Decision Matrix: A technique of evaluating finite number of alternatives against a multiplicity of factors.

Esteem Value: The properties, features or attractiveness which create a desire to possess the article.

FAST: Function Analysis System Technique; it looks like a network representation of various basic and secondary functions showing their inter-relationships.

Function: The term used to mean the purpose or use of a product.

Function Analysis: A technique to describe function of a product or system using two words-a verb and a noun.

Function Cost Matrix: A tool for identifying poor value areas by showing percentage importance of a function in a product and percentage cost spent in accomplishing that function.

Job Plan: A systematic procedure consisting of seven phases to carry out a Value Engineering Project.

Mental Roadblocks: Conditions of mind due to beliefs, resistance and fear etc. which retard creativity and idea generation.

Primary (Basic) Function: It is the basic or specific purpose for which the component or assembly was designed.

Paired-Comparison: A technique of determining relative importance of functions in Value Engineering by comparing two functions at a time.

Secondary Function: A function which does not directly contribute to the basic function or is only needed to support the achievement of a primary function playing enabling role.

Scope-lines: Used in FAST diagram to delineate the scope of responsibility of VE study.

Unnecessary cost: Also termed as hidden or invisible cost which does not improve the quality, features required by customer or the product utility but only increase the cost; for example, materials handling cost.

Use value: The properties which accomplish a use, work or service. The use value is equal to the value of the functions performed.

Value Engineering (Value Analysis): A systematic organised approach to determine the function of a product and system and find least cost ways of achieving it.,

Value Index: It is a ratio of worth of an article to its cost and is equal to $\frac{\text{Worth}}{\text{cost}}$. It may also be expressed as a ratio of relative importance of a function to its relative cost. (Value Index- the greater, the better.)

Vendor: Supplier of materials, products or services who can play an effective role in cost reduction and value improvement.

Worth: Relative importance of a function.

Consumer's Risk: Probability of accepting a bad lot.

Producer's Risk: Probability of rejecting a good lot.

OCC: Operating Characteristic curve.

AQL: Acceptable Quality Level.

LTPD: Lot Tolerance Per cent Defective.

AOQ: Average Outgoing Quality.

AOQL: Average Outgoing Quality Limit.

Control Limits: Limits if exceeded imply that the process is out of control.

11.19 SELF-ASSESSMENT QUESTIONS/EXERCISES

Value Engineering

- 1) Identify five products in your day-to-day life and determine reasons for poor value in them.

- 2) Applying the Function Analysis approach write down the basic functions of the following objects in two words:
 - i) Umbrella
 - ii) Ash Tray
 - iii) Paper Weight
 - iv) Wrist Watch
 - v) House.
- 3) Suppose the following five attributes are identified to evaluate a value alternative initial cost; functional performance; reliability and maintainability; product appearance and dependence on supplier. Use paired comparison approach to determine the relative importance of these attributes.
- 4) Identify the basic and secondary functions of a typewriter and arrange them in a descending order of importance.
- 5) Write an essay on how to organise value engineering function in an electronic industry.
- 6) Why are suppliers sometimes helpful in value analysis programmes? How can they help? Does it violate your concept of good business ethics to involve them in your problems?
- 7) Critically examine the following statement: "Value Engineering is more of a human relations, team building and motivation programme than anything else".
- 8) Study the following situation and attempt to answer the questions raised:

Thomas is a purchasing manager of a company making do-it-yourself power tools. The president of the company entrusted him the task of cost reduction through value analysis.

Thomas organised a display of all bought out parts and sub-assemblies and the fancy Drill-A-Thon, made of castings, stampings and turnings to draw the most attention. It had been designed and turned over to a supplier before purchasing became a separate profit centre under the president. In response to his queries to improve the assembly he got the following responses from three visiting salesmen.

The first company said that they would really gain price advantage if plastic instead of metal was accepted. The second company offered to make the product with fewer parts while the third company suggested that the best way was to assemble it within and they would supply parts at rock bottom prices.

Vice President of the Deen Dayal Industries Pvt. Ltd. who are the present suppliers rang up to Thomas to express his concern in offering the products his

company had been supplying for long to others and wondered whether these newcomers could make a better offer. He expressed a desire to be given a chance to reduce cost by trying value analysis. The chief design engineer also ridiculed the idea of going for plastic in place of metals and saw in it a conspiracy to cheapen their merchandise.

Thomas thus faces a conflict of view points. The president has given an ultimatum to reduce cost by at least 5 per cent, and his company's design experts are uneasy about outside interference. Would-be-suppliers are anxious in re-designing Drill-A-Thon to promote their own shops.

Now, answer the following queries:

- i) How can Thomas start a sound value analysis programme?
- ii) How should he handle the reactions of his present supplier?
- iii) In what way can he use the offered help of the would-be-suppliers who can be genuinely helpful?

Quality Assurance

- 9) What is the fundamental difference between the use of acceptance sampling plans and process control charts?
- 10) Why are averages of samples used in control charts rather than individual readings?
- 11) Comment on the following:
 - a) It is important to inspect the inspector.
 - b) As a quality improvement programme is established, cost of quality increases.
- 12) In the example in the text, the sampling plan A with $n = 35$ and $c=1$ has $\alpha = 0.16$ and $\beta = 0.14$, both too large to be acceptable.
 - a) What would happen to α and β if c were increased but n remained at 35?
 - b) Why do we need to increase both n and c to lower both α and β ?
 - c) If a batch contains 8% defective items, what is the probability that it would be rejected by the plan $n = 40$ and $c = 1$?
 - d) Find a sampling plan for $AQL = 0.008$, $LTPD = 0.01$, $\alpha = 5\%$, $\beta = 10$ per cent. [Ans: Follow example 7]
- 13) A manufacturing company produces a small product in lots of 10,000. They want to be 90 per cent sure of accepting the lot with fraction defective of 0.01 and 95 per cent sure of rejecting a lot with a fraction defective of 0.08. They do not know anything about sampling plan design. They intuitively decide that they will take a sample size of 100 and accept if not more than 4 defective items are found. The reasoning

is that it amounts to $4/100 = 0.04$ fraction defective which is roughly the mid point of their acceptable and rejectable quality.

- a) Does their plan achieve their goals? [Ans: NO]
 - b) Suggest a better plan. [Ans: sample size should lie between 67 and 82 and $c=2$. Take $n=75$ (midway)]
 - c) What are the AOQL values for these plans? [Ans: AOQL=0.0181]
- 14) A process which is under statistical control has a population mean of 10.000 cms and a population standard deviation of 0.002 cms. Determine.

- (a) The natural tolerance limits of the process

[Ans: 9.994, 10.006 cms]

- (b) If the specification limits are 10.002 ± 0.004 cms, what percentage of the product is defective, assuming that the process output deviations are normally distributed?

[Ans: 9.998, 10.006 (specification limits), total defective percentage = 4.56%]

- 15) In a single sampling plan the following data are known.

Lot size = 500, sample size = 71, acceptance number = 1, AQL = 0.005, LTPD = 0.05

Determine producer's risk and consumer's risk and draw OCC.

[Ans: $\alpha = 5\%$, $\beta = 13.07\%$]

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BLOCK-4

MATERIALS MANAGEMENT

UNIT 12 Purchase System & Procedure and Inventory Management

UNIT 13 Standardization, Codification and Variety Reduction

UNIT 14 Waste Management

BLOCK 4 MATERIALS MANAGEMENT

Effective Material Management involves maximizing materials productivity. This requires well coordinated and integrated approach towards various problems involving decision-making with respect to materials. Unit 12 discusses various purchase systems and procedures. Problems related to reducing inventories in the context of reducing uncertainties in demand and supply and reducing excessive material varieties are also discussed in the same Unit 12. The next Unit 13 discusses various standardization, codification and variety reduction methodologies for improving materials productivity and finally Unit 14 deals with, “how to minimize waste if it cannot be totally eliminated”.



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UNIT 12 PURCHASE SYSTEM AND PROCEDURE AND INVENTORY MANAGEMENT

Objectives

After completion of this unit, you should be able to:

- appreciate the need of professionalism in purchase, define the scope and objectives of the purchasing department of an organization and prepare the appropriate formats of input forms to the purchase departments for an efficient processing
- identify the demand characteristics of materials and their specifications, management policies, legalities, etc. to identify the suitable purchase procedures, decide on selection of suppliers, timing, price, quality and quantity and decide on the forms, records and reports relevant to purchasing
- evaluate purchase department, evolve the procedures for vendor evaluation, design the organizational structure for the purchase activity in an organization and introduce computerization of purchasing activities.
- understand the meaning of inventory and identify inventory related cost parameters, learn about various types of inventory policies, appreciate the role of selective inventory management, know the exchange curve concept for aggregate inventory planning and get a feel of some mathematical models of inventory analysis
- perform sensitivity analysis on a type of model, compute safety stocks
- understand the problems of slow moving items, appreciate the role of computers in inventory control and have a brief idea about recent developments in inventory management.

Structure

- 12.1 Introduction: Role of Purchasing Function
- 12.2 Inputs
- 12.3 Restraints and Factors
- 12.4 Purchasing Decisions
- 12.5 Purchasing Organisation
- 12.6 Procedures, Forms, Records and Reports
- 12.7 Evaluation of Departmental Procedures
- 12.8 Vendor Evaluation and Rating
- 12.9 Computerized Purchasing Systems
- 12.10 Purchasing in Government Organisations
- 12.11 Introduction to inventory Systems

- 12.12 Functions of Inventory
- 12.13 Classification of Inventory Systems
- 12.14 Selective Inventory Management
- 12.15 Exchange Curve and Aggregate Inventory Planning
- 12.16 Deterministic inventory Models
- 12.17 Probabilistic inventory Models
- 12.18 Inventory Control of Slow Moving items
- 12.19 Recent Developments in Inventory Management
- 12.20 Summary
- 12.21 Key Words
- 12.22 Self-assessment Exercises
- 12.23 Further Readings

12.1 INTRODUCTION: ROLE OF PURCHASING FUNCTION

From our daily life we know that every one of us depends on commodities and services supplied by other individuals or organisations. Similarly, every organisation, big or small, to varying extents, depends on materials and services from other organisations. **These materials and services are obtained through exchange of money. This process of exchange is known as purchasing.** In the present context, we shall concentrate on the purchase of materials. Materials constitute an important ingredient of inputs to the activities of several types of organisations. Industries require raw materials, components and equipments for their production, service organisations require supplies, spare parts are required for maintenance operations, and so on.

Furthermore, in most of the organizations, the value of materials as compared to other inputs to the system is high. In an industry, on an average about 40 to 60 percent of the total money is spent on materials and related services. Similar estimates about the large sums of money involved can be made for public works departments, electricity boards, developmental agencies and corporations etc.

With the increasing complexities in materials' characteristics and their usage vis-a-vis increasing competition, the purchasing function has emerged as a specialized organizational activity. In many organisations, it is regarded as a supportive functions. However, in order to attain the maximum contribution to the efficiency and effectiveness of an organisation, the purchasing should be treated as one of the functional areas.

Objectives

Purchasing principle are usually epitomized as buying materials of right quality, in the right quantity, at the right time, at the right price, from a right source and also at the right place. The main objectives are:

- 1) To make the user departments of the organisation from time to time aware of the range of the quality of materials available in the market and to maintain the right quality of purchased materials based on standards, technical specifications and suitability as determined by the user departments.
- 2) To procure at the lowest possible cost consistent with quality and service requirements.
- 3) To ensure the minimum possible investment in service operations related to purchased materials, such as transportation, inspection, storing and record keeping etc.
- 4) To maintain continuity of the supply to ensure that scheduled activities are not interrupted.
- 5) To integrate the requirements of all departments of the organisation in order to take the advantage of economy of scale wherever possible and to also avoid duplications of purchases resulting in wastes and obsolescence.
- 6) To create goodwill for the organisation through healthy buyer-supplier relationship.

Purchasing Functions

In order to meet the above objectives of the purchasing functions, the requisite inputs and possible restraints and factors must be identified. The purchasing function is responsible for a host of decisions. Figure I depicts the purchasing function.

In addition the outputs shown in Figure I, responsibilities of the purchasing department include other related activities:

- 1) Vendor Rating and Development, (2) Make or Buy, (3) Value Analysis, (4) Surplus Disposal, (5) Control and Audit, Maintenance and Development of Procedures, Forms, Records and Reports.

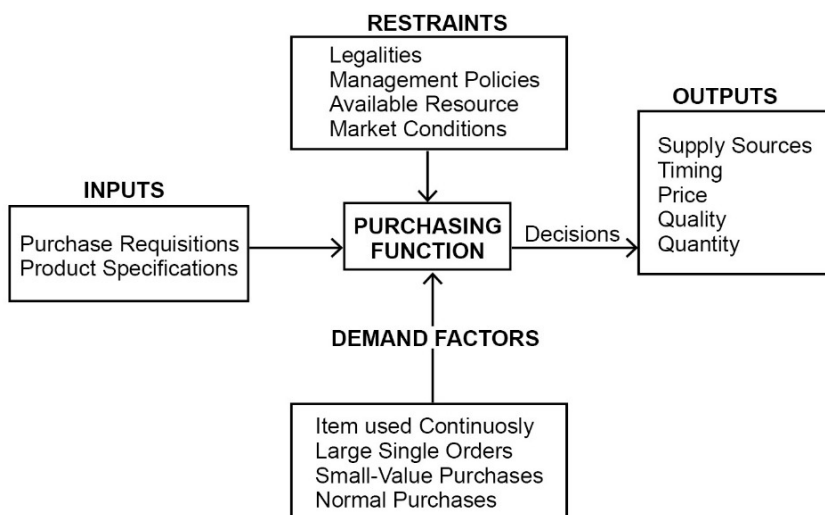


Figure I: Purchasing Decision Function

We shall discuss the relevant points with reference to Figure I in subsequent sections.

12.2 INPUTS

The Preparation of inputs constitute pre-purchasing activities and decide to a great extent the success of the purchasing system. The inputs to purchasing come in the form of requisition or indent from various departments and units of the organisation. The success of purchasing department depends upon the quality of these inputs and also upon the ability of the purchasing department personnel to analyze the inputs to the fullest extent, The most important inputs are: purchase requisitions and their accompanying product specifications.

Purchase Requisitions or Purchase Indents

A purchase requisition is the primary and authorization document describing the needed items. Most organizations have a standard requisition form for the use of all its departments. The format, however, may change from organization to organization.

The three most common types of the requisition forms are:

- a) standard purchase requisition,
 - b) travelling purchase requisition, and
 - c) bills of materials (BOM).
- a) **Standard Purchase Requisition Form:** This form is standard for a given organisation. Different organizations may use different formats. A standard purchase requisition form is used for non-recurring requirements of items and normally contains the following information:
- 1) Requisition number (for identification, may use blocked codes including a short code for the department, name of the requisitioner, year, serial no. etc.).
 - 2) Date of the requisition.
 - 3) Name of the department/section.
 - 4) Account to be charged (an appropriate head may be ticked out of standard account heads).
 - 5) Description and quantity of items.
 - 6) Purpose of the items.
 - 7) Date when items are needed.
 - 8) Approximate unit price and the total cost.
 - 9) Suggested suppliers' names and addresses.

- 10) Signatures of the requisitioner, head of the department, approving authority (as appropriate).

A sample format of standard requisition form is shown in Figure II. Space may also be provided for the purchasing department to record:

- 1 Purchase order no.
- 2 Shipping instructions
- 3 Delivery date and quantity delivered.

Figure II: Specimen of Standard Materials Requisition Form

STANDARD MATERIALS REQUISITION FORM					
Date				No.....	
Department/Section					
Account to be charged:					
Sl. No.	Description of Items	Quantity	Purpose	Approx. unit price	Approx. Total cost
TOTAL COST					
(1) Name		Suggested Suppliers		(3)	
Address		(2)			
.....					
(Requisitioner)		(Head of the Department)		(Approving Authority)	

- b) **Travelling Purchase Requisition:** This type of form is used by stores for recurring requirements for materials and standard parts. The requisition form is in the format of a card for a single item containing the information about the item (name and brief description, brief or coded names of the user department, annual usage rate, re-order point, order quantity) potential suppliers, records of receipts and issues, and so forth. The card can be used for many requisitions. When the stock level drops to or below the re-order point, the card is sent to the purchasing department for placing the order with the supplier. Sometimes a separate requisition form which is a brief version of standard form, is also used when it is not convenient to send the card. To identify that the item is requisitioned, a colored signal clip is attached with the card until the order is received. The entire transaction can be handled with minimum delay and without much of clerical paperwork.

A sample format of the travelling purchase requisition card is shown in Figure III.

Travelling Requisition Form

Material description: Order Quantity:
Part number: Re-order Level:
Annual usage: Suppliers: User Departments:

A ----

B ----

C-----

Requisitioned			Received		RFMARKS
Date	Quantity on hand	Quantity requested	Date	Quantity	

Figure III: Specimen Of Travelling Requisition Form

- c) **Bill of Materials:** This is a list of all items for a finished product and is prepared at the time of engineering drawing of the product. The bill of materials and the production schedule are sent to the purchasing department which computes the total requirements of each part for each period of the production. This eliminates the necessity of typing numerous requisitions for usually a large number of items.

Specifications

Specifications of an item intended to be purchased provide detailed description of the characteristics and features of the item. These must be provided by the requisitioning department by taking, if necessary, assistance from the purchasing department which has acquired specialization in the related matter. The major objectives of the specifications are: (1) to let the purchasing department understand exactly the features required in the item, (2) to let the supplier know exactly what the buyer wants, and (3) to permit the easier, quicker and accurate verification of items upon receipt.

Following are the common types of specifications used to describe and grade the items:

- a) **Market Grade:** Market grades are used in case of items bought and sold in a market place. Grading is done by comparison with a standard generally and widely accepted. Trade associations, commodity exchanges and government agencies establish and regulate such grades. Market grades are limited to natural products such as wheat, cotton, rice and lumber, etc. The suitability and success of this system, however, depend on the accuracy of grading and ability to ascertain the difference by inspection.
- b) **Commercial Standards:** These standards are used for the items above commodity level because of their widespread use. When a material or item is standardized with complete quality description and established by customs, and accepted by the government, its agencies and industry in

general, the material or item is said to be commercially standardized. Standard specifications have been prepared for many items by the Bureau of Indian Standards. Commercial standards have proved to be of great assistance in interchangeability for the user, and simplification of design, purchase procedure, inventory control and cost reduction. These play vital role in mass production.

- c) **Trade or Brand Names:** Trade or brand names are used by some manufacturers to establish the identity of various models produced and to protect them from other substitute. Branded products are simplest to buy, procedurally. Specifying an item by brand name limits the scope of competition and indicates a reliance upon the integrity and reputation of the supplier to provide consistent quality. This system of specification can be very economical for low-cost lot purchases.
- d) **Material Specifications:** These specifications define the physical or chemical properties desired in an item. Items such as metals (aluminum, steel, copper, etc.), drugs, oils and paints are examples of products with material specifications.
- e) **Performance Specifications:** Rather than describing an item physically or chemically, performance specifications describe the requirements about the performance characteristics. The seller is free to choose the materials, methods of processing and other details. These specifications are commonly used in case of equipments, machines and tools etc. This method, however, requires proper selection of supplier. The items supplied are tested to see that stated performance features are met. Purchase of computer system is a good example of this technique.
- f) **Samples:** In case of special items of non-repetitive nature or where quality requirement is not rigid or when the quantity of items is so low that it does not justify the formulation of specifications, specifications are established by specimens or samples. The supplier is supposed to match the sample. Difficulty arises if the samples are subject to change, physically or chemically. In case of mechanical parts for replacement where the identification marks are not easily read, this method of specifications by sample may be the only possible way of purchasing the item.
- g) **Blueprints:** A blueprint or engineering drawing is recommended for accompanying a purchase requisition when close tolerance or a high degree of mechanical perfection is required. Blue prints are used for mechanical parts, and for construction and other projects.
- h) **Combined Specifications:** Many products cannot be adequately described by a single type of specification. In such cases, a combination of two or more specifications may be used. Quite a few products for industrial uses are so complex that a combination becomes a practical necessity.

12.3 RESTRAINTS AND FACTORS

Restraints limit the alternatives available to purchasing department for its decisions. Similarly, the type of purchasing procedure adopted will depend on the factors related to the demand for the item. In this section, we shall discuss some of these restraints and the demand factors.

Purchasing decisions are restrained by legal considerations, management policies, resource availability and market conditions and so forth.

Legal Consideration

The purchasing department commits a good deal of finance when a purchase order is placed. It is, therefore, necessary to have sufficient understanding about the legal aspects of purchase. The Indian Sale of Goods Act, 1930 and the Indian Contract Act of 1872 cover some of important legal aspects. The important relevant laws are (1) Law of Agency, (2) Law of Contract, (3) Law pertaining to Sale of Goods, including Patent Laws, Warrantees, Trademarks, etc., and (4) Arbitration. Professional legal advice related to these laws is a must for major contracts involving large sums of money or extending over a long period of time like imports. Indian Chamber of Commerce and International Chamber of Commerce have codified general business terminology to minimize the friction between buyer and seller. In addition to the legal precautions, emphasis should be on mutual trust and confidence.

Management Policies (Centralized vs. Decentralized Purchases)

Management may choose between centralized and decentralized organization or a mixture of these two for purchases. Centralized purchasing has economic advantage due to specialization and input standardization and thus, is an attractive strategy for multi-plant and multi-location activities using related items. In addition it offers:

1. Development of specialized purchasing skills.
2. Consolidation of order quantities which can result in quantity and cash discount
3. Better control over inventory investment.
4. Less overlapping and duplication of effort.
5. Uniform quality and less variety of materials.

Centralized purchasing however, tends to be slow, rigid, and rule-bound, and may turn out to be very costly for low-value purchases. Also, if item required by various departments are unrelated and less frequently demanded, the advantages of centralization may be lessened. In such cases, management may decide to decentralize the purchase.

Resource Limitations

Finance is the major resource which can seriously influence the purchasing activities. The corporate finance is shared by all the departments of the

organisation and purchase department must operate within the allocated budget. This may lead sometimes to purchasing decisions somewhat less optimal than what it would have been had the purchase department been able to get the finance as and when desired. Thus sometimes the advantages of quantity discounts might have to be foregone in favour of overall financial planning of the organisation. Other resources such as manpower, storage space, and handling equipments also place limitations on purchasing decisions.

Market Conditions

The market conditions relate to short-term market situations which are influenced by supply and demand as well as overall national economy. Thus during shortage, the reliability of supply may be considerably more important than the price. The purchasing strategies should, therefore, change to cope up with these situations, and ability to anticipate these conditions measures, to a good extent, professionalism acquired by purchase personnel.

Demand Factors

Based on the demand pattern, the items can be grouped into four basic categories:

- 1) **Items Used Continuously:** Items that are continuously used with a fairly predictable demand can be handled under blanket purchase orders (also known as open-end purchase orders). A contract is negotiated with supplier(s) for a fixed period of time (six months or one year) with quantities, delivery dates, discounts etc. The price may be fixed, or kept open in which case the market price at the time of delivery will be applicable. Blanket orders conserve the time and effort of the purchasing department,
- 2) **Large Single Orders:** The situation of large single orders usually occurs in case of special machinery or other special goods, such as computers, vehicles and buildings etc. Considerable planning and evaluation are involved. The suppliers submit their bids with all relevant details and purchases are negotiated by comparison and evaluation of the bids.
- 3) **Small-value Purchases:** The low-cost infrequently used items are purchased usually by the concerned departments using petty cash or by identifying some small local supplier. For the value involved, it is not worth going through the complete cycle of purchase process.
- 4) **Normal Purchases:** Items other than mentioned above fall in this category and are handled by the normal procedure, i.e., following the complete cycle of the purchase process discussed above.

12.4 PURCHASING DECISIONS

With the purchase requisitions and specifications as inputs from the departments and sections of the organizations, the restraints from the external environment and the factors about the demand pattern, the purchasing department has to make several decisions. Some are purely operational while some relate to policy formulation having far-reaching impact on the long-term success of the organisation. In this section we shall discuss the operational decisions. Policy related decisions will be covered in subsequent sections.

From purchase requisitions, the purchasing department generates purchase orders which is a legal document. Purchase order forms vary in their format and their routing through the organisation. A purchase order should contain at least the following:

- 1) Purchase order number (for identification).
- 2) Date of issue.
- 3) Name and address of supplier receiving the order.
- 4) Quantity and description of item(s).
- 5) Required delivery date.
- 6) Shipping instructions.
- 7) Price and payment terms.
- 8) Other conditions governing the order.

A sample of the purchase order is shown in Figure IV

PURCHASE ORDER

No. Date:

.....

.....

.....

Date.....

REF: Quotation No..... Dated

S. No.	Description	Quantity required	Unit	Rate Rs. P.	Amount Rs. P.
1					
2					
:					Total Value

Payment Terms:

Delivery Terms:

Terms related to Sales Tax.

Other Information:

Copy to: All concerned departments

Purchase Officer

Figure IV: Specimen of Purchase Order

We shall now discuss some of the decision function leading to preparation of the purchase order.

Supplier Selection

Information on external sources of supply can be obtained from numerous references:

(a) industrial advertisements of the supplier appearing in newspapers and periodicals, (b) supplier catalogues, (c) supplier salesmen, (d) trade journals, (e) trade directories prepared by government agencies and trade associations, (f) list of suppliers approved by the government agencies, (g) enquiries through advertisements or individual communications, and (h) records of the organizations past purchases.

After compiling the information about suppliers for the needed item, relative proficiency of each potential supplier must be assessed on the basis of comparative quotations of price, quality, quantity, delivery, and other services. Other relevant variables are the supplier's management capability, technical ability, production capacity, quality of service, and financial stability. The purchase order is then issued to the most promising supplier. The information about other suppliers can be stored for future references.

Timing of Purchases

An organization is primarily interested in an adequate supply of material at the best price consistent with quality requirements. Timing is not a critical concern when the purchases are made in price stable market but it becomes critical in unstable price market situation. Following approaches may be adopted while trying to time the purchases in response to market conditions:

- a) **Speculative Buying:** It involves purchasing in excess of foreseeable requirements in order to make profit (or imputed profit) from rising prices. Opportunities arise for such a purchase when price falls temporarily and the organisation has sufficient working capital to finance such speculative purchases.
- b) **Forward Buying:** It involves purchasing in economical quantities exceeding current requirements, but not beyond actual, foreseeable requirements. This approach is often used when prices are stable over time. It is adopted to obtain a favourable price, to get quantity discounts, to secure items when they are available, and to protect against prospective shortages. It, however, assumes the risk of increased inventory holding cost which ties up working capital.

Hand-to-mouth Buying: This practice is resorted to satisfy only immediate current requirements and may be uneconomical. This may be suitable in case of high- value items. It is not recommended for normal operations.

There are inherent risks in all these approaches in the environment of fluctuating market and price instability. Two techniques may be used to reduce the financial risk.

- a) **Time-budgeting Purchases:** Using time-budgeting purchases, an organisation can frequently purchase an item over a long periodic cyclic fluctuation at an average price very close to average market price. This is accomplished by purchasing small quantities over short operating periods of equal length.
- b) **Hedging:** The organization purchases the required quantity on the spot or open market and at the same time sells the same quantity in the future market contracting to deliver at a future date in order to mitigate the risk associated with fluctuating prices. This approach, however, can be used in case of those items for which organized commodity markets or exchanges exist.

Price Determination

Price per unit of an item comprises the unit purchase price, transportation cost, handling cost, inspection, insurance and the administrative variable cost. The right price simply means the lowest possible total price for the organisation.

The typical approaches for price determination are published price lists, competitive bidding, and negotiation. Price lists published by the suppliers give initial indication of the price. In competitive bidding, the requests for bids are sent to several suppliers. Usually (not always) the lowest bidder gets the order. Normal practice requires at least three competitive quotations wherever possible. Generally competitive bidding is most applicable to standardized products that are widely used and are produced to stock.

Bids are normally secured when the size of an order exceeds some minimum amount.

Negotiation is the approach resorted to when time is too short, the number of bidders is too small, value of purchase is high, willingness to compete is lacking, or the specifications are too vague. In such circumstances, the buyer contacts the potential supplier and negotiates for the fair price and prompt delivery. An advance planning and analysis are expected to bring satisfactory results out of negotiation.

While determining the price, shipping terms should also be clarified. The shipping terms established (1) who will pay the freight charges, (2) when does the buyer take the legal title to the goods, and (3) who will prosecute loss and damage claims against carriers. There are numerous terms of shipment, but the most common ones are:

- a) **F.O.B. (Free on Board) Buyer's Plant:** The buyer takes the title to the goods when the goods are delivered at his plant and supplier pays all

transportation charges and processes all claims against the carrier for damages or loss of goods.

- b) **F.O.B. Seller's Plant:** The buyer takes the title when goods are loaded onto the carrier and he pays all transportation charges as well as negotiates all freight damage claims with the carrier.
- c) **F.O.B.Seller's Plant—Freight Allowed:** Legal responsibilities same as in F.O.B. seller's plant, but the supplier pays the freight charges.
- d) **C.I.F. (Cost of Insurance and Freight) Contracts:** The price includes cost of materials, insurance and freight.
- e) **F.A.S. (Free Alongside Ship):** Used in shipping by sea where supplier is responsible for getting goods to the ship, and the buyer takes title as well as all responsibilities thereafter.

Further, purchase contracts can be of fixed price (quite common), cost plus contract (no definite limit to costs) or blanket order (for six months or one year) type.

Discounts: An important aspect of price determination involves discounts that can be secured. Following types of discounts are common:

- 1) **Trade Discount:** To protect certain distribution channel when it is economical to buy from the distributor rather than from the manufacturer.
- 2) **Quantity Discount:** For purchasing worth beyond certain amount of money.
- 3) **Seasonal Discount:** For purchasing in off-season.
- 4) **Cash Discount:** For prompt and full payment.

Quality and Quantity

The process of determining right quality in purchasing implies striking a balance between technical specifications and economic considerations. The right quality has no absolute meaning but is specified in relation to a purpose. As mentioned above most of the technical specifications are decided by the requisitioning department. The purchasing department should be instrumental in taking the quality decisions by making available various market grades, trade names, commercial standards etc. and corresponding prices and sources of supply to the requisitioning departments to enable them to specify quality of items. Once the quality standards are specified, the purchasing department makes arrangement in collaboration with the requisitioning department for the inspection of the items after delivery. Sometimes, inspection is performed by an organizational representative in the vendor's plant. On-site inspection can save time and money while minimizing operational delays from the inferior quality. For normal items supplied in lots, inspection for acceptance is carried out by sampling.

Procedures should be established for handling inferior quality. Should the shipment be returned to the supplier and contract cancelled? Should the buyer rework the item to an acceptable quality and bill the supplier? Should only rejected items be returned for replacement and acceptable items retained? Such issues must be resolved in advance to maintain a long-term relationship.

After determining the quality, the next important step is to determine how much quantity to buy and when. For items continuously used, the purchasing department can collect the projected demands from various departments and then can incorporate these details into the blanket purchase order. For large single orders, there is not much to decide about the quantity. Small-value purchases are made as and when need arises. For normal purchases usually two quantities govern the ordering decision: reorder-point and order quantity. When the stock goes to or below reorder-point an order for the required quantity is placed.

Reorder-point = Safety stock + average demand during the lead-time

$$\text{Order quantity} = \sqrt{\frac{2AD}{H}}$$

where.

A= fixed cost of ordering (Rs./order)

D= average annual demand (unit/year)

H = holding cost(Rs./unit/year)

Safety stock depends on the variation of demand and can be taken as 3 times the standard deviation.(Safety Stock = 3Std Dev)

In case of production components, the determination of right quantity can be linked with the concept of Materials Requirement Planning(MRP).

14.5 PURCHASING ORGANISATION

Purchasing department is usually under the General Manager at par with other functional departments such as engineering, finance, accounts, manufacturing and marketing etc. Sometimes it is kept along with other related departments like stores, inventory and materials control, under materials manager who in turn is under General Manager. Choice of an organizational structure depends on the volume of work and value of the purchase. A good structure encourages the assignment of specific responsibilities, specific authorities and smooth chains of command of delegation. It should lead to the development of policies that permit routine decisions to be made by subordinates.

Within purchase department, the structure may be worked out using following approaches:

- a) **Organization by Function:** It is based on the principle that job should be organized so as to promote maximum possible specialization of skills. Total purchasing job is broken up on the basis of specialization, such as (1) processing of purchase requisitions, (2) floating enquiries, (3) selection of suppliers, (4) preparation of purchase orders, (5) receipt inspection and storing, (6) liaison with accounts section, (7) records maintenance etc. Each job, or a group of jobs, is assigned to individual or group of individuals who specialize in that work. This approach has obvious advantages but suffers from the disadvantage of people getting bored doing the same kind of jobs for a long time, and sometimes it leads to bureaucratization.
- b) **Organization by Product:** The items purchased are classified into groups and each group is assigned to a team of personnel who specialize in purchase of that particular type of the materials. For example, a team may be specialist in buying raw materials, while other in components and sub-assemblies, and so forth.
- c) **Organization by Location :** This is applicable for the organizations which are large and have several plants. Each plant may have a purchasing department under the overall supervision of the central purchasing department.
- d) **Organisation by Stage of Manufacturing:** In case of manufacturing, sometimes it is advisable to organise the purchase activities according to the stage of manufacturing, e.g. raw materials, parts and sub-assemblies etc.

14.6 PROCEDURES, FORMS, RECORDS AND REPORTS

Procedure

By procedure we mean the entire set of steps in which a purchase transaction is carried through from its inception to its conclusion. These steps together form the purchase policy of an organization. Since there are wide variations among industries, companies, organizations, products and personnel, it would not be feasible to establish a single set of procedures which would apply to all cases. The following basic steps, however, must be taken in one way or another:

- 1) Receipt and analysis of requisition to assess the need and description of requirement.
- 2) Selection of possible sources of supply.
- 3) Determining the time, price, quality and quantity.
- 4) Placing the order.
- 5) Following up and expediting of the order.

- 6) Checking the invoice and receiving the order.
- 7) Processing discrepancies and rejections after inspection.
- 8) Communicating with accounts' section for payment.
- 9) Closing completed records.
- 10) Maintenance of records and files.

A schematic purchase procedure involving some of these steps is shown in Figure V.

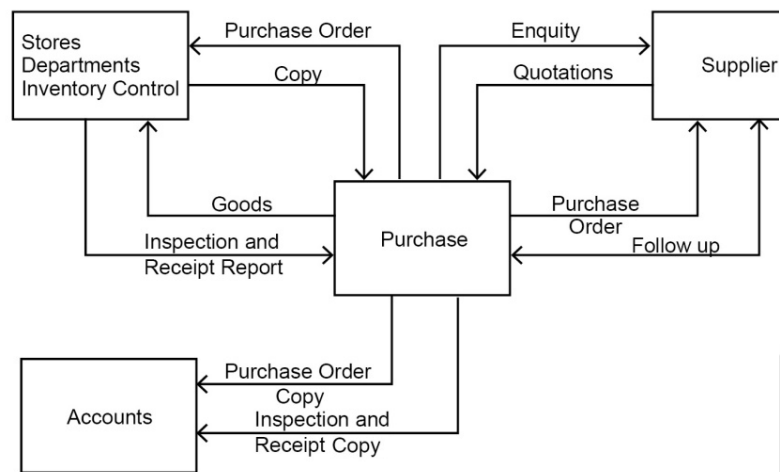


Figure V: A Schematic Diagram Of Purchase Procedure

Purchase Forms

Forms are very important tools for purchasing department to standardize the communication with internal departments of the organization and external agencies such as supplier and local government bodies, etc. The number of forms required depends on the size of the organisation, the purchasing system employed in the organisation, and the accounting and internal control methods in effect. Normally there should not be too many forms as they create confusion and red tapeism. Certain links of communication can be sent in copies of some forms (as shown in Figure V) instead of individual forms. The forms should incorporate the principles of good design to facilitate data entry and data retrieval, to minimize the possibility of errors, and finally, to be just economically sufficient in size and number of entries required.

Purchase forms for the following functions are usually employed (some of which have already been exhibited).

- 1) Purchase requisition
- 2) Request for quotation
- 3) Purchase order
- 4) Follow-up

5) Receiving and Inspection.

In addition, some other forms are also used by some large organizations. Among such forms are: acknowledgement for quotation received, change of order notice, purchase contract and sample test report etc.

Purchase Records

Since purchasing is a repetitive process, accurate records are a necessity for efficient operation. These records provide a history of what has been done in the past (supplier, price, discounts and quality of delivery etc.) and provide a wealth of information upon which to base future decisions. Maintaining a good-record system will increase operating costs but expectedly it should bring some handsome savings in the long run.

Most purchasing departments maintain the following basic records:

- 1) **Purchase Order Log:** It contains a numerical brief record of all purchase orders issued. It contains purchase order number, supplier's name, brief description of purchase, total value of the order etc. The log makes it possible to summarise several administrative data.
- 2) **Open Order File:** Contains the status of all outstanding orders. It contains purchase requisition, purchase order and follow-up data.
- 3) **Close Order File:** Contains a historical data of all completed purchases.
- 4) **Vendor Record :** Contains the names and addresses of suppliers, materials that a supplier can supply, delivery and quality records.
- 5) **Commodity Record:** Such record is maintained on each major material or service that is purchased repetitively. It shows the list of suppliers, annual usage rate, price, orders placed, orders received and disbursements to the departments.
- 6) **Contract File :** Contains the purchase records of items under a term contract. It is specially important when the contract is an open one, against which orders may be placed.

Purchase Reports

Since the purchasing department handles a sizeable proportion of corporate finance, it is desirable to have some summary reports periodically (quarterly, half-yearly or annually) available to the management. Some of the important reports are:

- 1) Total value of purchase.
- 2) Allocation of purchase value against major items.
- 3) Allocation of purchase value against each requisitioning department.
- 4) Budget for purchase for the next year.

- 5) Proposals for revisions of budget in current year.

In addition, the purchasing department brings out the report for its own use. They are:

- 1) Vendor Performance Report
- 2) Pattern of Consumption of materials.
- 3) Pattern of market prices.

12.7 EVALUATION OF DEPARTMENTAL PROCEDURES AND VENDORS

Evaluation of the purchasing department is essential for the economic health of the organization. At the same time, a good proportion of the efforts in purchasing activities are not immediately visible and so the evaluation becomes rather difficult. In any case, a consistent effort towards this aspect must be kept on with the following objectives of evaluation:

- 1) Performance improvement of the department.
- 2) Aid to Organization.
- 3) Easy coordination amongst departments.

Establishing evaluation criteria is also very difficult. Following criteria can be combined for an overall picture of purchasing performance:

- 1) Cost-Purchase Comparison (annual cost of purchasing department divided by the total value of purchases).
- 2) Cost per Order (total purchasing department cost divided by the number of orders).
- 3) Return on Investment (net savings per rupee. spent on purchasing).
- 4) Quality Criteria (measured by number of rejects).
- 5) Quantity Criteria (measured by down time).
- 6) Price Criteria (comparison with other organization or standard price indexes).

The evaluation standards can be based on past performance, budgeted performance, or performance of departments in other organization to judge what is being done as compared to what should have been done.

12.8 VENDOR EVALUATION AND RATING

It is not always easy to identify good suppliers. Records maintained or procured from some other sources about the vendors help in their evaluation and rating. Usually a combination of price, quality, quantity, delivery time

and service etc. giving relevant weightages to these factors is used to rate the vendors. In addition, a checklist can be used to facilitate rating from department standpoints. Some of the points are mentioned below:

Reliability

- 1) Is the supplier reputable, stable and financially strong?,
- 2) Are the supplier's integrity and ability above doubt?
- 3) Is the supplier going along with product improvement?
- 4) Is the supplier's competitive strength as to price and quality, etc. proved by past experience?

Technical Capabilities

- 1) Can the supplier provide assistance as to application engineering?
- 2) Can the supplier provide assistance as to analytical engineering?
- 3) Can the supplier provide design assistance?
- 4) Can the supplier handle special needs and contribute to improve product efficiency/basic processes?

Convenience

- 1) Can the supplier help reducing acquisition costs through personal visits, telephone calls, incoming inspections, rejection of defects and spoilage, etc?
- 2) Can he offer other related products?
- 3) Is he qualified to help in solving difficult problems?
- 4) Does the supplier package his product conveniently?

Availability

- 1) Does the supplier assure delivery in time?
- 2) Are his stocks locally available, and or at short notice?
- 3) Is the supplier's location advantageous?
- 4) Can he plan his supply to minimise inventory?
- 5) Can he be depended on for a steady flow of materials?

After-sales Service

- 1 Does the supplier have a service organization?
- 2 Is an emergency service available?
- 3 Are parts available, when needed?

Sales Assistance

- 1 Can the supplier help building mutual markets?
- 2 Will he recommend our products?
- 3 Does the use of supplier's product enhance appearance of our products?

Vendor Evaluation

Recognizing that there is a need for having good vendor, it is essential that supplies are obtained from vendors after an evaluation of his capabilities. The buyer, who has to do the evaluation, is faced with two different situations;

- 1 Evaluating the performance before the vendor has delivered anything.
- 2 Evaluating the performance of vendor after the deliveries have been made.

The latter one is normally called Vendor Monitoring and the former Vendor Evaluation.

In case of Vendor Evaluation the buyer lacks the direct evidence on the results achieved by the vendor and must get his information in other ways. This includes (1) general reputation of vendor, (2) data from other buyers, (3) vendor surveys.

Vendor Rating

Product quality submitted by vendors has always been evaluated and used as a factor in making purchasing decisions. Recently, the evaluation has been formalized by the use of vendor rating formulas which provide a quantitative measure of vendor quality. These ratings are primarily meant to provide an over all quality rating of a vendor for use in reviewing, comparing, and selecting vendors. Vendor rating is not a tool for making decisions on submitted lots.

To create a single numerical quality score is difficult because there are several inputs, each involving its own unit of measure:

- 1 The lot quality, expressed as lots rejected versus lots inspected.
- 2 The parts qualities, expressed as per cent defective.
- 3 The characteristic qualities, expressed in numerous natural units, e.g., rupees per square cm., per cent active ingredient, MTBF (mean time between failures) etc.
- 4 The economic consequences of bad quality, expressed in rupees.

The National Association of Purchasing Agents, New York, has published three alternative vendor rating plans:

- 1 **Categorical Plan:** This is a non-quantitative system in which buyers hold a monthly meeting to discuss vendors and rate each as plus, minus, or neutral.
- 2 **Weighted-point Plan:** Each vendor is scored on various factors like quality, price and service etc. These factors are weighted and a composite rating is then calculated for each vendor. The details of this performance evaluation scheme are as follows:

- i) **Quality Rating:** Quality Rating for a consignment

$$R_Q = \frac{Q_1 + Q_2 X_1 + Q_3 X_2}{Q} \times 100$$

where,

Q = Quantity supplied, Q_1 = Quantity accepted Q_2 = Quantity accepted with concession, Q_3 = Quantity accepted with rectification Q_4 = Quantity rejected and $Q = Q_1 + Q_2 + Q_3 + Q_4$ and X_1 and X_2 are weightage factors each less than 1.

- ii) **Price Rating:** Price rating for a consignment:

$$R_P = \frac{P_L \times 100}{P}$$

where, P_L = Lowest price quoted, P = Price agreed by supplier

- iii) **Delivery Rating:** Delivery rating for a consignment:

$$R_D = \frac{\text{Promised delivery time (days)} \times 100}{\text{Actual delivery time (days) of the full consignment}}$$

Rating in excess of 100 shall be equated to 100.

- iv) **Quantity Rating:** Quantity Rating for a consignment:

$$R_{Qty} = \frac{\text{Qty supplied within stipulated delivery time}}{\text{Quantity promised}} \times 100$$

$$= \frac{Q}{Q_p} \times 100$$

- v) **Service Rating:** Service Rating, RS , is to be assigned by Purchase Department as per the following table for each consignment.

Sl. No.	Service Factor	Max. Score
1	Cooperativeness and readiness to help in emergencies	a_1
2	Readiness to replace rejected material	a_2
3	Providing support documents in time	a_3
4	Promptness in reply	a_4
5	Acceptance of terms without complaints	a_5

where $a_1 + a_2 + a_3 + a_4 + a_5 = 100$

vi) **Composite Vendor Performance I Rating:**

$$VPR = f_1R_O + f_2R_P + f_3R_D + f_4R_{Qty} + f_5R_S$$

where, $f_1 + f_2 + f_3 + f_4 + f_5 = 1$

Fixing of Weightage Factors: In order to implement this scheme, it is necessary to fix the weightage factors $X_1, X_2, a_1, a_2, a_3, a_4, a_5, f_1, f_2, f_3, f_4$ and f_5 as suited to the organization.

3 Cost-ratio Plan: This plan compares vendors on the total rupee cost for a specific purchase. Total cost includes price quotation, quality costs, delivery costs, and service costs. The final rating is in rupees of net value cost. The net value cost is the product of the adjusted unit price and the number of units. The adjusted unit price incorporates three cost ratios.

- i) The quality cost ratio reflects the relative cost of quality.
- ii) The delivery cost ratio reflects the relative cost of placing and receiving an order. It also includes a promises-kept penalty based on a ranking of past performance of vendors.
- iii) The service cost-ratio reflects the technical, managerial, and field service competence of the vendor.

All three of these plans recognize quality in the rating of vendors but the rating is not restricted to product quality.

Vendor Relations

The ultimate objective in vendor quality assurance is the production of materials which so adequately conform to the buyers, requirements that there is no need for extensive acceptance or corrective procedures by the buyer. The activities needed to achieve this objective include:

- 1 Communication of essential and helpful information, design, specifications, standards and practices etc.
- 2 Communication of engineering changes, changes in specifications etc.
- 3 Developing methods for detecting deviations from standards promptly.
- 4 Helping the vendor in resolving quality problems. In case of vendors like sub-contractors and ancillaries, rendering necessary technical assistance as well.
- 5 Providing for use of vendor quality data in lieu of incoming inspection.
- 6 Using multiple vendors for major procurements of items.
- 7 Developing methods for identifying the qualified vendors, and for eliminating those who are unable to meet the quality requirements.
- 8 Reviewing the performance of the vendor through vendor rating or other plans and following up on the chronically poor vendors.

The guiding principle in vendor relations is the spirit of what is best for the partnership. The supplier must be made to realise that it is not sufficient to accept the returns willingly or to negotiate the disposition of materials not delivered to the specifications. The supplier should view such instances objectively and work constructively with the buyer to correct the conditions that brought about the delivery of unsatisfactory material or service.

12.7 COMPUTERISED PURCHASING SYSTEM

The attractive characteristics of computers such as high speed, huge storage, quick retrieval accuracy, versatility and diligence on the one hand and increasing complexities in purchasing on the other make an excellent match for computerization of purchasing system. The declining cost of computer system is an additive factor.

Although there are no complex arithmetic computations involved in purchasing, the requirements of quick processing of requisition, follow up and payment etc. find a computer of immense help. In this section, we shall discuss broad outline of computerization of the system (not the computer technology).

Let us visualize that the computer has the following files:

- 1 Inventory file for each item.
- 2 List of the suppliers (alongwith their performance history).
- 3 Budget allocation for each department.
- 4 Master purchase file condensing the previous purchases (item-wise, department-wise, supplier-wise, price and quality etc.)

In addition, the computer has facilities to print and (may do so on a preprinted stationery) the quotation request, purchase order, follow up and inspection report etc.

When a requisition is received, the relevant data are entered through the appropriate programme. Now a days, the screen and template designs are proving much more convenient and fool proof. The computer checks the inventory status of the items and if in-stock, items are issued and inventory record is updated. If not in the stock, a programme finds the classification of the item, that is, whether it is a continuously used item or a special item. From the suppliers list, it finds the suppliers who can supply the items and prints quotation requests. If it is a special item, then human intervention will of course be needed to float the enquiries. The programme also checks the budget of the department and account head to which the sum is to be debited. The data from quotations are entered and the computer displays the comparative statement. It will select the supplier and print the purchase order. Upon receipt, it will update the inventory of the item. In addition, computers

are very useful for monitoring the status of the purchase order to assist in follow-up actions.

So we see that computer performs all the actions displayed in Figure V and generates the reports as desired above. In addition it is very useful in processing exceptional reports, such as budget is over, orders not supplied in time and payments not made in time etc.

It may be mentioned that most of the computers, specially small and mini-computers, offer a host of utilities which are very useful for computerization of tasks like purchase.

Computerization of purchase (such as receiving, issuing, instruction, stores, inventory and handling etc.) can easily bring the desired coordination among other functions of materials management as well as among other departments of the organization such as production, design, engineering, finance and accounting, marketing etc. through suitable design of data base and information systems.

12.10 PURCHASING IN GOVERNMENT ORGANISATIONS

With the aim of providing the best possible service to the society out of the limited resources and following its policy of mixed economy, the Government of India has itself entered into manufacturing and other types of commercial and trading activities. To gain the advantages of centralized purchase all Governmental purchase operations are controlled by a central agency, the Directorate General of Supplies and Disposal (DGS & D), New Delhi headed by its Director General (Supplies and Disposal) under the Ministry of Supply, Government of India. The DGS & D is responsible for all purchase of materials of all kinds and functions as a purchasing and inspection agency on behalf of:

- 1 All Ministries, attache's and subordinate offices of Government of India.
- 2 All State Governments and their departments.
- 3 All local bodies, such as, Municipal Corporations, District Boards, etc.
- 4 All Quasi-public Institutions, Statutory Corporations and Public Sector industrial undertakings may also avail of the services of the DGS & D.

It also makes purchases from foreign countries through its subsidiaries like the Indian Supply Mission in London and Washington. It also purchases from East European and South-Eastern countries on trade agreements.

Organisation Set-up of DGS & D

The role of the DGS & D is very wide and, for smooth and efficient functioning, it is divided into following wings:

- a) Supply

- b) Inspection
- c) Progress
- d) Disposal.

The organisation has regional offices located at Kolkata, Mumbai, Kanpur and Chennai. Besides, there is a regional-office at Mumbai exclusively for textiles. The regional offices are empowered to purchase a large number of items provided the individual demand for them does not exceed a pre-fixed amount. All items financed through foreign loans are purchased by the HQ irrespective of their nature and value.

In addition to the activities carried through its wings, the DGS & D performs the following functions and has directorates and offices all over the country.

- 1 Public Relations and Publications.
- 2 Standardization and Quality Control.
- 3 Development of Indigenous Sources of Supplies.
- 4 Purchases from Cottage and Small Scale Industries.
- 5 Registration of Suppliers.
- 6 Termination, Suspension and Black-listing of Suppliers.
- 7 Rate and Running Contracts.
- 8 Payment Procedure.
- 9 Indent Processing.

12.11 INTRODUCTION TO INVENTORY SYSTEMS

Concept of Inventory .

‘Inventory’ may be defined as ‘usable but idle resource’. If resource is some physical and tangible object such as materials, then it is generally termed as stock. Thus stock or inventory are synonymous terms though inventory has wider implications.

Broadly speaking, the problem of inventory management is one of maintaining, for a given financial investment, an adequate supply of something to meet an expected demand pattern. This could be raw materials, work-in-progress, finished products or the spares and other indirect materials.

Inventory can be one of the indicators of the management effectiveness on the materials management front. Inventory turnover ratio (annual demand/average inventory) is an index of business performance. A soundly managed organization will have higher inventory turnover ratio and vice-versa.

Inventory management deals with the determination of optimal policies and procedures for procurement of commodities. Since it is quite difficult to imagine a real work situation in which the required material will be made available at the point of use instantaneously, hence maintaining, inventories becomes almost necessary. Thus inventories could be visualized as 'necessary evil'.

Inventory Related Cost

An inventory system may be defined as one in which the following costs are significant:

- a) cost of carrying inventories (holding cost)
 - (b) cost of incurring shortages (stock out cost)
 - (c) cost of replenishing inventories (ordering cost)
- a) **Cost of carrying inventory** :This is expressed in Rs./item held in stock/unit time. This is the opportunity cost of blocking material in the non-productive form as inventories. Some of the cost elements that comprise carrying cost are—cost of blocking, capital (interest rate); cost of insurances; storage cost; cost due to obsolescence, pilferage and deterioration etc. It is generally expressed as a fraction of value of the goods stocked per year. For example, if the fraction of carrying charge is 20% per year and a material worth Rs.1,000 is kept in inventory for one year, the unit carrying cost will be Rs. 200/item/year. It is obvious that for items that are perishable in nature, the attributed carrying cost will be higher
- b) **Cost of incurring shortages**: It is the opportunity cost of not having an item in stock when one is demanded. It may be amounting to lost sales or back logging. In the backlogging (or back ordering) case the order is not lost but is backlogged, to be cleared as soon as the item is available on stock. In lost sales case the order is lost. In both cases there are tangible and intangible costs of not meeting the demand on time. It may include lost demand; penalty cost; emergency replenishment and loss of good-will etc. This is generally expressed as Rs./item short/unit time.
- c) **Cost of replenishing inventory**: This is the amount of money and efforts expended in procurement or acquisition of stock. It is generally called ordering cost. This cost is usually assumed to be independent of the quantity ordered, because the fixed cost component is generally more significant than the variable component. Thus it is expressed as Rs./order.

These three types of costs are most commonly incorporated in inventory analysis, though there may be other costs parameters relevant in such an analysis such as inflation and price discounts etc.

Importance of Inventory Management

Scientific inventory management is an extremely important problem area in the materials management function. Materials account for more than half the total cost of any business and organizations maintain huge amount of stocks much of which could be reduced by following scientific principles. Inventory management is highly amenable to control. In the Indian industries there is a substantial potential for cost reduction due to inventory control. Inventory being a symptom of poor performance we could reduce inventories by proper design of procurement policies by reduction in the uncertainty of lead times by variety reduction and in many other ways.

12.12 FUNCTIONS OF INVENTORY

As mentioned earlier, inventory is a necessary evil. Necessary, because it aims at absorbing the uncertainties of demand and supply by 'decoupling' the demand and supply sub-systems. Thus an organisation may be carrying inventory for the following reasons:

- a) Demand and lead time uncertainties necessitate building of safety stock (buffer stocks) so as to enable various sub-systems to operate somewhat in a decoupled manner. It is obvious that the larger the uncertainty of demand and supply; the larger will have to be the amount of buffer stock to be carried for a prescribed service level.
- b) Time lag in deliveries also necessitates building of inventories. If the replenishment lead times are positive then stocks are needed for system operation.
- c) Cycle stocks may be maintained to get the economics of scale so that total system cost due to ordering, carrying inventory and back logging are minimized. Technological requirements of batch processing also build up cycle stocks.
- d) Stocks may build up as pipeline inventory or work-in-process inventory due to finiteness of production and transportation rates. This includes materials actually being worked on or moving between work centers or being in transit to distribution centers and customers
- e) When the demand is seasonal, it may become economical to build inventory during periods of low demand to ease the strain of peak period demand.
- f) inventory may also be built up for other reasons such as: quantity discounts being offered by suppliers, discount sales, anticipated increase in material price and possibility of future non-availability etc.

Different functional managers of an organisation may view the inventory from different viewpoints leading to conflicting objectives. This calls for an integrated systems approach to planning of inventories so that these conflicting objectives can be scrutinised to enable the system to operate at

minimum total inventory related costs—both explicit such as purchase price, as well as implicit such as carrying, shortage, transportation and inspection costs. Concepts and techniques useful in analysis of these problems to arrive at sound policy decisions are the focal point of presentation in this unit.

12.13 CLASSIFICATION OF INVENTORY SYSTEMS

Lot Size Reorder Point Policy

Under this operating policy the inventory status is continuously reviewed and as soon as the inventory level falls to a prescribed value called 'Reorder Point', a fresh replenishment order of fixed quantity called Economic Order Quantity (EOQ) is initiated. Thus the order size is constant and is economically determined. This is one of the very classical type of inventory policies and a lot of mathematical analysis has appeared on this type of policy. Figure VI shows the typical stock balance under this type of inventory policy. The solid line in this figure represents the actual inventory held in practical situation with a finite lead time, **the lead time being defined as the time delay between the placing of a replenishment order and its subsequent receipt**. The broken line indicates the inventory that would be held in the ideal situation if no lead time existed. Lot size and reorder point are the two decision variables involved in the design of the policy.

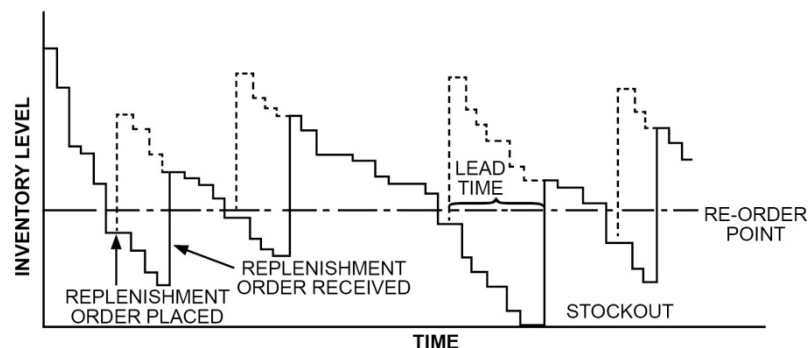


Fig VI. Typical Inventory Balances for EOQ-Reorder Point Policy

Fixed Order Interval Scheduling Policy

Under this policy the time between the consecutive replenishment orders is constant. There is a maximum stock level (s) prescribed and the inventory status is reviewed periodically with a fixed interval (T). At each review an order of size Q is placed which takes the stock on hand plus an order equal to the maximum stock level. Thus order quantity could vary from period to period. This policy ensures that when the level of stock on hand is high at review, a smaller size replenishment order is placed. Figure VII shows the typical stock balances under this fixed reorder cycle policy. S , the maximum stock level and T the review period are the decision variable under this policy

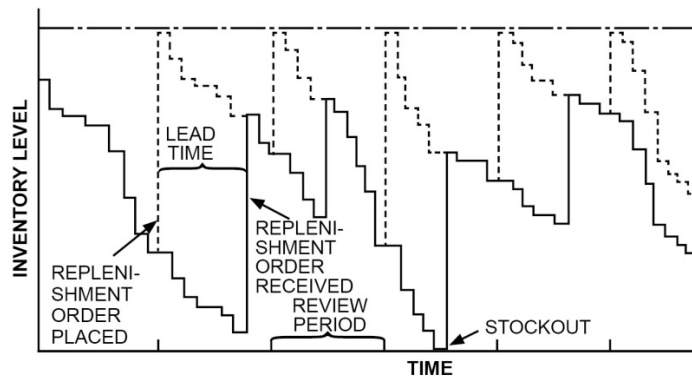


Fig VII. Fixed Reorder cycle Policy

Optional Replenishment Policy (s - S Policy)

This is very popularly known as the (s, S) policy. Figure VIII shows the typical stock balance under this policy. The status of stock is periodically reviewed and maximum stock level (S) and minimum stock level (s) are prescribed.

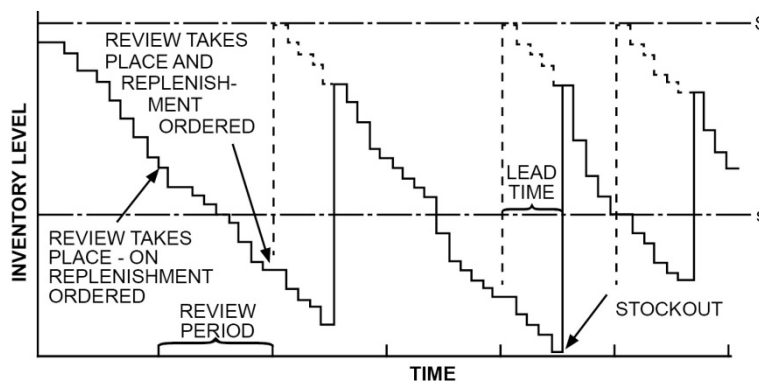


Fig VIII- Typical Inventory Balances in (s-S) Policy.

If at the time of review, the stock on hand is less than or equal to s, and order of size Q is placed so that stock on hand plus an order equals the maximum stock level S. If stock on hand at review is higher than s, no order is placed and the situation is reviewed at the time of next review period. S, s and T (review period) are the decision variables in the design of such inventory policy.

Other Types of Inventory Systems

There may be other policies which may be special cases of the policies mentioned above or may be a combination of these policies. As a special case of (s, S) policy we may have (S-1, S) policy or one-for-one order policy when the maximum stock level may be upto S and whenever there is demand for one unit, a replenishment of one unit is ordered. Such a policy may be quite useful for slow moving expensive items.

We may use a combination of lot-size reorder point policy and fixed interval order scheduling policy. Yet another variation of inventory policy could be multiple reorder point policy where more than one reorder point may be established.

Other types of inventory systems may be static inventory systems when a single purchase decision is to be made which should be adequate during the entire project duration. Such decisions are not repetitive in nature. Other initial provisioning decisions may be with respect to repairable assemblies such as engines and gearboxes etc. in a bus which may have to be overhauled and for which we have to find adequate number of spare engines to be provided initially.

The right choice of an inventory policy depends upon the nature of the problem; usage value of an item and other situational parameters. We must first select an operating policy before determining optimal values of its parameters.

12.14 SELECTIVE INVENTORY MANAGEMENT

Role of Selective Inventory Control

One of the major operating difficulty in the scientific inventory control is an extremely large variety of items stocked by various organizations. These may vary from 10,000 to 100,000 different types of stocked items and it is neither feasible nor desirable to apply rigorous scientific principles of inventory control in all these items. Such an indiscriminate approach may make cost of inventory control more than its benefits and therefore may prove to be counter-productive. Therefore, inventory control has to be exercised selectively. Depending upon the value, criticality and usage frequency of an item we may have to decide on an appropriate type of inventory policy. The selective inventory management thus plays a crucial role so that we can put our limited control efforts more judiciously to the more significant group of items. In selective management we group items in few discrete categories depending upon value; criticality and usage frequency. Such analyses are popularly known as ABC, VED and FSN Analysis respectively. This type of grouping may well form the starting point in introducing scientific inventory management in an organization.

ABC Analysis

This is based on a very universal Pareto's Law that in any large number we have 'significant few' and 'insignificant many'. For example, only 20% of the items may be accounting for the 80% of the total material cost annually. These are the significant few which require utmost attention.

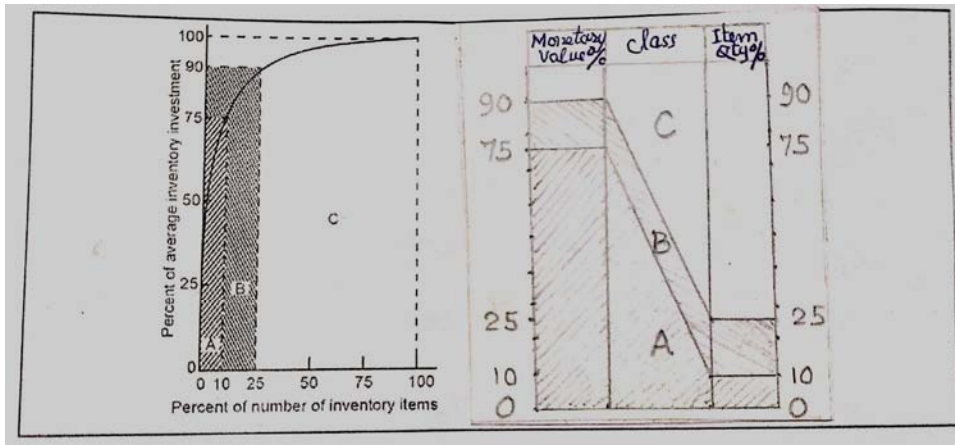


Fig. ix: ABC Analysis

Fig. ixa: Classification of Items

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A- 10% items claiming approximately 75% of annual usage(Rs)

B-15% items claiming approximately 15% of annual usage(Rs)

C -75% items claiming approximately 10% of annual usage(Rs)

Figure IX shows a typical ABC analysis showing percentage of number of inventory items and percentage of average inventory investment (annual usage value). Annual usage value is the demand multiplied by unit price thus giving monetary worth of annual consumption. It can be seen from this figure that 10% items are claiming 75% of the annual usage value and thus constitute the 'significant few'. These are called A- class items. Another 15% items account for another 15% annual usage value and are called B-class items. A vast majority of 75% items account for only 10% expenditure on material consumption and constitute 'insignificant many' and are called C-class items. To prepare an ABC type curve we may follow the following simple procedure:

- Arrange items in the descending order of the annual usage value. Annual usage value = Annual demand x Unit price.
- Identify cut off points on the curve when there is a perceptible sudden change of slope or alternatively find cut off points at top 10% next 20% or so but do not interpret these too literally— rather as a general indicator.

A very simple empirical way to classify items may be adopted as follows:

$$\text{Average annual usage value } \bar{X} = \frac{\text{Total material cost per year}}{\text{Total number of items}}$$

A-Class items $\geq 6\bar{X}$

C-Class items $\leq 0.5\bar{X}$

In between we have B-class items.

Once the items are grouped into A,B and C category, we can adopt different degree' of seriousness in our inventory control efforts. A class items require almost continuous and rigorous control, these are subjected to highest level of control, supervision and management. Whereas B-class items may have relaxed control, these are subjected to medium level of control, supervision and management. C-class items may be procured using simple rules of thumb, as usual and these are not subjected to elaborate control and management since the cost of effort is not worth it.

Other Variants of ABC Analysis.

VED Analysis

This analysis attempts to classify items into three categories depending upon the consequences of material stockout when demanded. As stated earlier, the cost of shortage may vary depending upon the seriousness of such a situation. Accordingly the items are classified into V (Vital), E (Essential) and D (Desirable) categories. Vital items are the most critical having extremely high opportunity cost of shortage and must be available in stock when demanded. Essential items are quite critical with substantial cost associated with shortage and should be available in stock by and large. Desirable group of items do not have very serious consequences if not available when demanded but can be stocked items for the sake of efficiency and less fatigue.

Obviously the % risk of shortage with the 'vital' group of items has to be quite small- thus calling for a high level of service. With 'Essential' category we can take a relatively higher risk of shortage and for 'Desirable' category even higher. Since even a C-class item may be vital or an A-class item may be 'Desirable' we should carryout a two-way classification of items grouping them in 9 distinct groups as A-V, A-E, A- D, B-V, B-E, B-D, C-V, C-E and C-D. Then we are able to argue on the aimed at service-level for each of these nine categories and plan for inventories accordingly.

FSN Analysis

Not all items are required with the same frequency. Some materials are quite regularly required, yet some others are required very occasionally and some materials may have become obsolete and might not have been demanded for years together.

FSN analysis groups them into three categories as Fast-moving, Slow-moving and Non-moving (dead stock) respectively. Inventory policies and models for the three categories have to be different. Most inventory models in literature are valid for the fast-moving items exhibiting a regular movement (consumption) pattern. Many spare parts come under the slow moving category which have to be managed on a different basis. For non-moving dead stock, we have to determine optimal stock disposal rules rather than inventory provisioning rules. Categorization of materials into these three types on value, criticality and usage enables us to adopt the right type of

inventory policy to suit a particular situation. In this unit, we shall mainly be developing some decision models more appropriate for A- class and fast-moving items. Later on a brief discussion on the inventory management of slow-moving items will be given.

SDE Analysis: Based on the problems of procurement, it classifies the items into scarce, difficult and easy classes

HML Analysis: Based on the price instead of usage value, it classifies the items into high, medium and low classes.

XYZ Analysis: Based on the value of stocks in hand (i.e. capital employed to procure inventory) it classifies the items as X category whose inventory values are high, Z category whose values are low and Y category in between.

SOS Analysis: This analysis is based on seasonality of items as seasonal (available only for a limited period depending on the season) and off seasonal.

12.15 EXCHANGE CURVE AND AGGREGATE INVENTORY PLANNING

Concept of Exchange curve

Exchange curve (or optimal policy curve) is an effective technique to look at the inventories at an aggregate level in the organisation. It is a plot between the total number of orders (TO) per year and the total investment in inventories (TI) per year. The rationale is that for an optimal inventory policy the trade-off between total inventory and total procurement effort as indicated by the total number of replenishment orders per year must be made such that if total number of order are prescribed, we minimize total investment in inventories. Alternatively, if the total investment in inventories (TI) is prescribed then a rational inventory policy must aim at minimizing (TO). Optimal inventory policy must exchange (TI) for (TO) in such a manner that

$$(TI) \cdot (TO) = K = \text{constant}$$

Value of constant **K** is given by

$$K = \frac{1}{2} \left[\sum_{i=1}^N \sqrt{D_i} V_i \right]^2$$

where D_i = Annual requirement of i th item, V_i = Unit price for i th item,
 $i = 1 \dots N$

Thus a plot between (TI) and (TO) is a rectangular hyperbola and is called as

'Exchange curve' or 'optimal policy' curve, Figure X shows a typical exchange curve for a situation where the ordering cost is not explicitly

known. It shows that any point on the exchange curve is an optimal trade-off between investment in inventories and total number of orders.

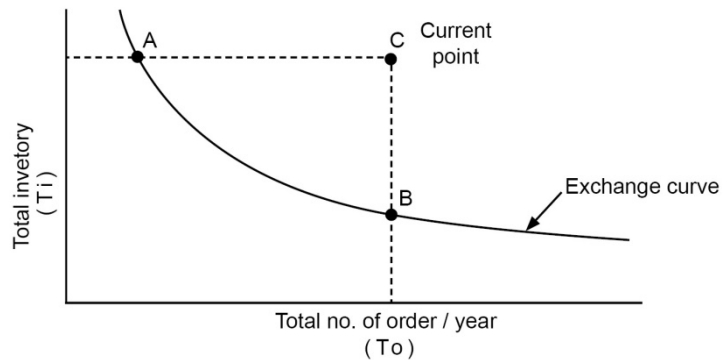


Fig X. Exchange Curve

Uses of Exchange Curve

Exchange curve is an effective instrument for aggregate inventory analysis to quickly determine the rationality (or otherwise) of our existing stock provisioning policies.

We first plot the exchange curve by computing the value of K for a chosen group of items. Then we determine the total number of orders (TO) and total investment in inventories (TI) under current practice.

If the current practice is at point C (in Figure X) above the exchange curve then it shows that our present procurement policies are not rational. If we want to rationalize these then there are two possible paths-AC or BC; so that we reduce inventory to B for the same ordering effort or reduce number of orders to A for the same inventory. Thus an exchange curve is a useful device at macro-level.

12.16 DETERMINISTIC INVENTORY MODELS

Classical EOQ Model

In this section we discuss some elementary inventory models with deterministic demand and lead time situations. The purpose is to provide an illustration of the mathematical analysis of inventory systems. The most classical of the inventory models was first proposed by Harris in 1915 and further developed by Wilson in 1928. It is very popularly known as EOQ (Economic Order Quantity) model or 'Wilson's Lot Size formula'.

When dealing with stocked items, the two important decisions to be made are- how much to order and when to order. EOQ attempts to provide answer to former while the Reorder point (RoP) provides the answer to the latter.

The following assumptions are made in the standard Wilson lot size formula to obtain EOQ:

- Demand is continuous at a constant rate
- The process continues infinitely.
- No constraints are imposed on quantities ordered, storage capacity, budget etc.
- Replenishment is instantaneous (the entire order quantity is received all at one time as soon as the order is released).
- All costs are time-invariant.
- No shortages are allowed
- Quantity discounts are not available.

The inventory status under EOQ-RoP policy is continuously reviewed. Figure XI (a) shows the behaviour of such a simple system whereas Figure XI (b) shows the total system cost behaviour highlighting the conflicting trend of ordering and inventory carrying costs. EOQ aims at minimizing total system cost.

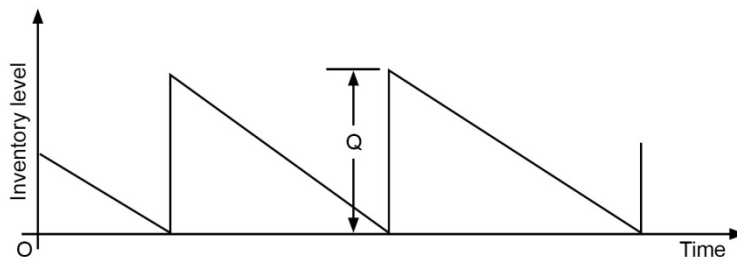


Fig. XI (a) Inventory behaviour under classical EOQ model

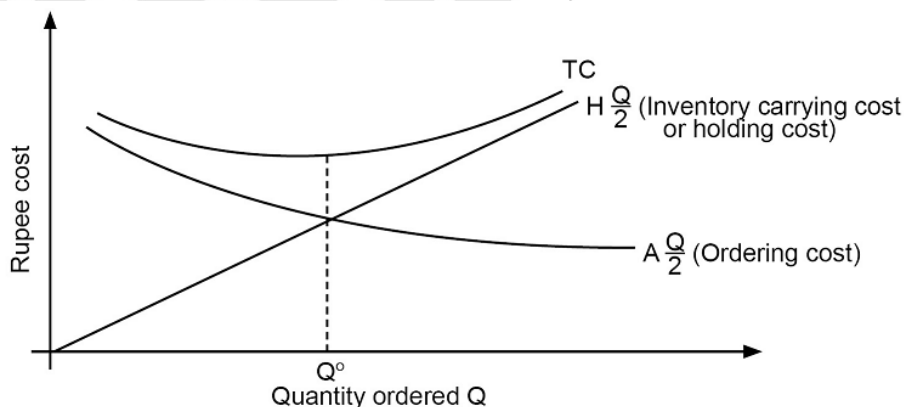


Fig. XI (b) Total Cost Curve Under EOQ model

Let us use the following notation in developing the classical EOQ model:

D = Demand rate; unit per year.

A = Ordering cost; Rs./order.

C = Unit cost, Rs. per unit of item.

r = Inventory carrying charge per year.

H = Annual cost of carrying inventory/unit item = $r.c$.

TC=Total annual cost of operating the system Rs./year (objective function).
Q=Order quantity, Number of units per lot (decision variable).

Since demand is at uniform rate average inventory is $Q/2$ throughout the year and the total number of orders are (D/Q) per year. Thus total annual cost of operating the systems consisting of carrying cost and ordering cost can be written as:

$$TC = A\left(\frac{D}{Q}\right) + \frac{H \cdot Q}{2}$$

Differentiating TC w.r.t. Q, we have

$$\frac{d(TC)}{dQ} = \frac{-AD}{Q^2} + \frac{H}{2}$$

Equating it to zero, we get:

$$Q^0 = EOQ = \sqrt{2AD/H} \text{ also } \frac{d^2(TC)}{dQ^2} = +\frac{2AD}{Q^3} = \text{positive quantity}$$

Hence Q is minimum at $Q = Q^0 = \sqrt{2AD/H} = EOQ$ { $Q^0 = Q^{\text{optional}} = EOQ$ }

Putting the value of Q in the equation of TC, we get $TC(\text{min}) = \sqrt{2AHD} = TC^0$

Due to convex nature of total cost curve, it is obvious that $Q^0(EOQ)$ gives the global minimum total cost. It can also be seen that EOQ is obtained at the point of intersection of ordering cost and carrying cost in Figure XI(b).

Some interesting insight may be obtained using this classical system:

- i) If ordering cost is of high tendency, the optimal policy is to have high EOQ thus raising average inventory level.
- ii) If r or C are high leading to high value of H, the tendency will be to go for smaller lot sizes.

r may vary from 0.15-0.30 and will depend on the nature of item, 'A' the ordering cost should be marginal ordering cost while H should be based on total purchased cost of the items.

Finite Replenishment Rates(See also Section 6.3)

We will now relax the assumption (d) of the classical EOQ model and permit finite replenishment rate (staggered deliveries). When the rate of procurement is P in units / year and the demand rate is D, in units/year, the build up of inventory is at a rate (P-D) due to simultaneous consumption. It is obvious that $P > D$ for inventory to build up. Figure XII shows the inventory behaviour with finite supply rate. The stock builds up to a maximum level I during supply period t_s , after which stock depletion takes place at rate D. It can be

seen that $I = t_s(P-D)$, $t_s = \frac{Q}{P}$ and thus $TC = A(D/Q) + H \frac{Q}{2} \left(1 - \frac{D}{P}\right)$

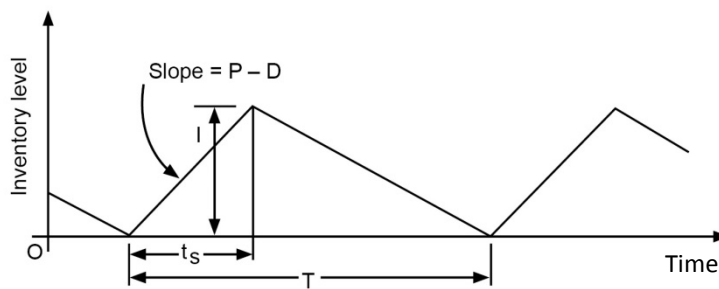


Fig XII- Inventory Behaviour Under Finit Replenishment rate.

For minimum TC we get, $Q^0 = \sqrt{\frac{2AD}{H(1-D/P)}}$ and $TC^0 = \sqrt{2ADH(1-D/P)}$

Some interesting observations can be made about the behaviour of such systems. These are:

- i) Q^0 under finite replenishment rates are higher than Q^0 under classical EOQ model for the same values of other parameters.
- ii) Total system cost under optimal Q^0 is lower than corresponding total system cost under EOQ model. Thus staggering the supplies always reduces inventory level and total operating system cost provided other cost parameters remain the same.
- iii) As $P \rightarrow \infty$, Q^0 and TC^0 obtained are same as in standard Wilson's formula of instantaneous replenishment.
- iv) At $P=D$, $Q^0 \rightarrow \infty$, $TC \rightarrow 0$. Thus if we can have a fully devoted reliable supplier, then placing a single supply order of large size but matching supply rate with the demand rate is the optimal decision. Under such a system, no stocks are built, no replenishments are made, no shortages are incurred. This would seem to be an ideal system towards zero-inventory provided we know our requirements for sure and we have a dependable source to supply us at the rate to match the requirement. This brings out the role of dependable source of supply as an important asset to materials management function.

Planned Backlogging

Let us now consider the effect of relaxing assumption (f) of classical Wilson's model by permitting back logging (shortages or back ordering) at a unit shortage cost of S in Rs./unit short/year. In such a case negative inventory shows the backlogging position. The order quantity Q is partly used to clear the backlogging level B and $(Q-B)$ is the maximum stock level. Figure XIII shows the inventory behavior under planned backlogging.

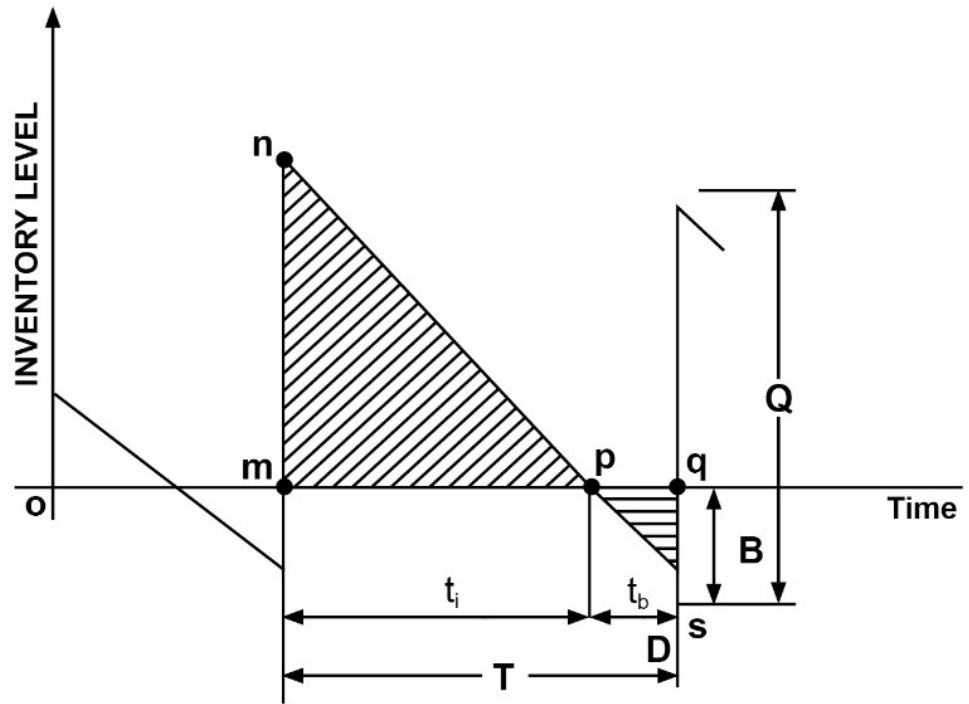


Figure XIII: Inventory behavior with planned backlogging.

Inventory is maintained for duration t_i and demands remain backlogged for duration t_b . Total cycle time of each replenishment cycle is

$$T = t_i + t_b = Q/D$$

$$t_i = \frac{Q-B}{D}, t_b = B/D$$

It can be seen that, average inventory = $\frac{(Q-B)^2}{2Q}$ and average back order level = $B^2/2Q$

TC = Total annual system cost

$$= A(D/Q) + H \frac{(Q-B)^2}{2Q} + S \cdot \frac{B^2}{2Q}$$

Optimal values of Q and B can be obtained for minimum value of TC as follows:

$$Q^* = \sqrt{\frac{2AD}{H}} \cdot \sqrt{\frac{H+S}{S}}$$

$$B^* = \sqrt{\frac{2AD}{S}} \cdot \sqrt{\frac{H}{H+S}}$$

$$TC^* = \sqrt{2ADH} \cdot \sqrt{\frac{S}{H+S}}$$

$$\text{Maximum stock level} = Q^* - B^* = M^* = \sqrt{\frac{2AD}{H}} \times \sqrt{\frac{S}{H+S}}$$

Some useful observations could be made about the behaviour of inventory system with planned backlogging as follows:

- Total system cost is lower with planned backlogging than the corresponding total system cost under classical Wilson's lot size formula. Thus for a deterministic system with finite backlogging cost, it is economical to plan for backlogging. It can be seen that at $S \rightarrow \infty$, the model reverts to classical EOQ model.
- EOQ under backlogging is higher and maximum stock level is lower than the corresponding values under classical Wilson's lot size model.
- If $S = 0$ then $B^* = Q^* = \infty$. This means that with no charge for back orders one would keep piling up unfilled demand until the backlog gets infinitely large. Then one single order would be released to satisfy all accumulated demand. However, considering intangible cost of backordering such as loss of goodwill etc. it is debatable whether there are situations when the unit cost of shortages (S) is really zero.

Model with Quantity Discounts

Frequently, the vendors offer quantity discounts on bulk purchases to encourage users to place orders in large quantities. Quantity discounts may be all unit discounts or incremental quantity discounts. In all unit discounts entire order quantity is purchased at lower unit price. If order size is higher than or equal to the stipulated conditions. In incremental case only quantity exceeding the threshold point is charged at lower unit cost. The immediate reaction may be to avail the discount and place bulk orders but if we see the total system cost, our decision may be otherwise. There may be a single or multiple quantity discounts. Figure XIV shows total system costs under four discounts.

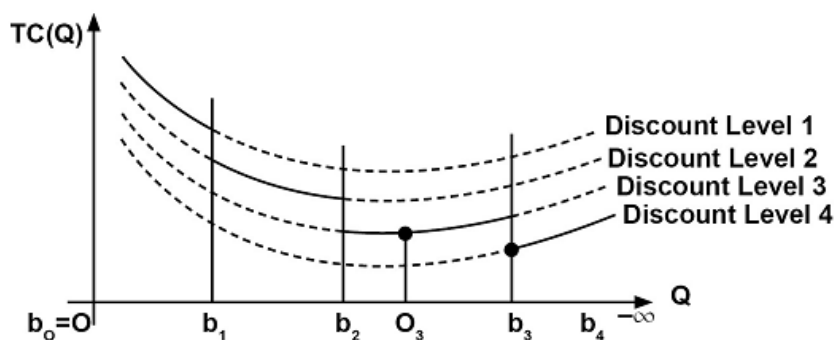


Fig XIV- Total Cost Curves Under Quantity Discounts.

The broken lines show the total cost curves without price break whereas solid lines show the actual total cost if price break takes place. The larger the number of price breaks, the more difficult it becomes to analyse the situation as more alternatives are to be evaluated. The important point to be made in

such situations is that individual situation is to be analyzed to judge which of the options is suitable to avail discount and place bulk order to make it realizable— reject the offer and place small order at higher unit price or place order at the minimum possible quantity at which discount becomes valid. Any alternative is optimal if that minimizes the total system cost. For example, it can be easily seen from Figure XIV that for this case the minimum total system cost occurs at $Q^* = b_3$ is the minimum quantity at which discount level4 is applicable.

Sensitivity Analysis

It may not be operationally very convenient to stick to EOQ if it is an odd figure. Then one may like to know the repercussions on total system cost if one deviated either way from Q^0 . This is done through sensitivity analysis. If Q_a is actual order quantity, $Q_a = b \cdot Q^0$ where b is sensitivity parameter. If $b=0.8$ then actual Q_a is $1.025 Q^0$ and if $b = 1.2$ then Q_a is $1.016 Q^0$. Obviously the TC will increase over TC^0 in either case. If we substitute Q_a as bQ^0 in total cost expressions in the classical EOQ model, we can easily get the following relationship.

$$\frac{TC_a}{TC^0} = \frac{1 + b^2}{2b} = p$$

Where TC_a is actual cost with order size being Q_a . It can be seen that at $b=1, p=1$. If b is allowed to vary within 0.9 to 1.1 then p will be within 1.005 indicating that $\pm 10\%$ deviation in EOQ leads to less than half a percent increase in TC. Thus TC is not very sensitive to EOQ and for operational convenience we should be able to vary EOQ within $\pm 10\%$ of Q^0 without adversely affecting total system cost. (Proof is shown below)

$$TC_a = \frac{D}{bQ} A + \frac{1}{2} bQ \cdot H$$

$$TC^0 = \sqrt{2DAH}$$

$$\text{and } Q^0 = \sqrt{\frac{2DA}{H}}$$

$$\text{Solving we get } -\frac{TC_a}{TC^0} = \frac{1 + b^2}{2b}$$

Case I let $b = 0.9$

$$p = \frac{TC_a}{TC^0} = \frac{1.81}{1.8} = 1.005$$

Case II let $b = 1.1$

$$p = \frac{TC_a}{TC^0} = \frac{2.21}{2.20} = 1.005$$

i.e. $\pm 10\%$ variation in EOQ amounts to 0.5% rise in total cost.

12.17 INVENTORY CONTROL OF SLOW MOVING ITEMS

Nature of Slow Moving Items- As stated earlier, slow moving materials are those which are not regularly demanded and their movement off the shelf is very occasional, say once in six months or so.

Examples of slow moving materials can be—spare parts and some special purpose materials for projects required only for a certain kind of project activity. Inventory models valid for fast moving models are not applicable for slow moving items due to lack of regular demand pattern. Generally slow moving items are quite expensive and therefore one has to first decide whether to keep them all in stock and if to keep them in stock then in what quantity. Further difficulty of slow moving parts is the initial over-buying decision which could take years to remedy the situation due to rarely occurring demands.

Some Inventory Policies for Slow Moving Spares

We shall illustrate our approach to manage the inventory of slow moving items with spares inventory problem as a substantial percentage of spares come under the slow moving categories. Some of the strategies that could be possibly adopted for efficient inventory management of slow moving spares are as follows:

- a) If spares are required only at pre-specified time such as at the time of major scheduled maintenance for replacement, then it is better not to stock them but to place procurement order sufficiently well in advance, keeping lead times in mind, so that these arrive just in time when these are needed
- b) If the part gives adequate warning of impending break down, then also the best policy is to place an order the moment we get the warning. Adequate warning refers to the case when the lead time required is less than the warning time. This shows that major improvements in slow moving inventory are possible by cutting down the lead times.
- c) For inadequate warning spares we must keep the stock. Generally maximum stock level will be 1 or 2 or one-for-one ordering policy is very useful. This means placing an order for one spare when one is consumed.

12.18 RECENT DEVELOPMENTS IN INVENTORY MANAGEMENT

Multi-echelon Inventory Systems

The inventory models described in the preceding sections pertained to situations where the stock is located at a single place. In practice the stock may be distributed over several locations. For example in a multi-project

organisation, there may be a central store and a number of field stores or project stores. Such types of inventory systems are called 'Multi-echelons inventory Systems'. Since the inventory in all the locations belong to the same system, it is better to look at the inventory management for the system as a whole rather than treating each storage location independently.

Recently a lot of attention has been given by the researchers to the analysis of such multi-echelon inventory systems. Important decisions concerning the design and operation of such systems are the number of echelons, number of storage points at each echelon (level), location of central store, optimal inventory policy to be followed by each storage location and stock redistribution policies etc. For very expensive slow moving item such as complex assemblies it may be desirable to locate the inventory at the central store rather than at the project (field) store provided the item is standardized and is usable at each locations. Detailed mathematical analysis of multi-echelon inventory systems tends to be rather complex and is beyond the scope of this unit.

Materials Requirement Planning(Refer Section 6.5)

12.19 SUMMARY

Purchasing, in ordinary sense, is the procurement of materials, components, machines, equipments and supplies etc. on payment, In the present environment of frequently varying price conditions and increasing material variety and competition, the purchasing function needs professionalism to reduce the total investment in purchase while making the required materials of right quality available on time. The purpose of this unit is to present and discuss various aspects of purchasing to achieve this professionalism. Major topics discussed include: scope and objectives of purchasing, inputs, environmental and management factors influencing the purchasing decisions, purchasing decisions, procedures, forms, records and reports, procedure evaluation, vendor evaluation, and organisation for purchasing. The presentation and discussions are aimed at an efficient information flow amenable for computerization.

An efficiently designed purchase system, with appropriate procedure, forms, and information flow, can generate the reports with required contents intended for specified destinations at various levels of management in the organisation.

This unit has also attempted to highlight the role of inventory management in the successful operation of any production or service system. Functions of inventory and various inventory related costs parameters have been identified. Various operating inventory policies have been described. ABC/VED/FSN analysis concepts have been outlined to enable selective control on inventories and the role of exchange curve to quickly detect the irrationality of existing procurement practice has been highlighted. Some

deterministic models to determine EOQ are presented and sensitivity of classical EOQ model is analyzed. Impact of demand/lead time variability on reorder point and buffer stock has been explained. Problems of slow moving items inventory control has been identified and some guidelines have been given. Recent developments in inventory management have also been touched.

12.20 KEY WORDS

Average Down Buying: Policy of purchasing items at a moment when the market dips sharply in the course of gradual price change.

Bill of Materials (BOM): A list of all items incorporated into a finished product produced by the organization. It is prepared on the basis of engineering drawing.

Bill of Lading: A document signed by the shipping agency acknowledging the receipt of certain specified goods for carriage and embodying an undertaking that goods will be delivered to the consignee.

Blanket (or Open- end) Purchase Order: A purchase order in the form of a contract for continuously used items for a fixed period (usually a year) with delivery dates and quantities. The prices may be negotiated for the whole period or kept open in which case the prevailing market price applies.

Commercial Invoice: Statement showing the details of items and their prices. It is a preliminary document sent by supplier to buyer and is used by the buyer to check the goods received.

DGS and D (Directorate General of Supplies and Disposal): The central purchasing organization of Government of India for public buying.

Forward Buying: Policy of purchasing items in economical quantities exceeding current requirements, but not beyond actual foreseeable requirements.

Hand-to-mouth Buying: Policy of purchasing items only to meet immediate short term requirements.

Hedging: Practice of entering simultaneously into two transactions of a like amount— a cash transaction and a futures transaction. The cash transaction involves the current exchange of the buyer's cash for the physical goods and the futures transaction involves the buyer's sale of a future contract on the item with promised delivery at a specified date in future.

Letter of Credit: An arrangement by which the obligation to pay an exporter is undertaken by a bank.

Negotiation: Purchaser approaches the suppliers for price determination. It is used when the number of bidders is small, value of purchase is too high and time is too short for competitive bidding or willingness to bid is lacking.

Product Specifications: Detailed description of the characteristics and features of an item. Some common types are: blue-prints, market grades, commercial standards material specifications and performance specifications etc.

Reciprocal Buying (or Reciprocity): Practice of giving preference in buying to those suppliers who are customers of the buying organisation.

Speculative Buying: Policy of purchasing items in excess of foreseeable requirements in order to make a profit from rising prices.

Standard Purchase Requisition: A requisition form used by internal departments of an organisation to raise the indents for non-recurring materials. The completed form is submitted to the purchase department.

Travelling Purchase Requisition: A requisition card maintained continuously for each item and used to procure currently needed materials and parts. It originates from stores or inventory control section.

ABC Analysis: Arranging items according to annual usage value in three categories A, B and C to identify significant few and insignificant many.

Backlogging: Process of accumulating unsatisfied demand till fresh replenishment of stock is made available.

Buffer Stock: Extra safety stock needed to absorb variation in demand and supply to provide cushion.

Carrying Cost: Cost associated with holding one unit in inventory for one time period (year).

Exchange Curve: A curve indicating optimal trade off between total inventory and total number of orders (also called optimal policy curve.)

EOQ: Economic Order Quantity; the quantity for procurement which will result in minimum total system cost associated with carrying, ordering and back logging.

FSN Analysis : Classification of items according to frequency of usage in Fast, Slow and Non-moving groups.

Inventory Turnover Ratio: Annual demand divided by average inventory.

Lead Time: Time that elapses between placement of an order and actual receipt of materials.

MRP: Materials Requirement Planning; a system of order scheduling for dependent demand situation.

Multi-echelon Inventory System: A system of inventory control where the stock is located at different levels (echelons) at different locations.

Optional Replenishment Policy: An operating policy based on maximum and minimum stock levels with periodic review, popularly known as (s,S) policy.

Ordering Cost: Cost associated with placing a purchase order expressed as Rs./order.

Quantity Discount : A sales promotion strategy by vendor in which bulk purchases can be made at lower unit prices.

ROP: Reorder point; the stock level when the action for replenishment of stock be initiated by placing an order.

Service level: Percentage of times an item is available in stock when demanded.

VED Analysis: Process of grouping items into Vital, Essential and Desirable categories depending upon the criticality of the items.

12.21 SELF- ASSESSMENT EXERCISES

I Review Questions

- 1 What are the common objectives of the purchasing function?
- 2 What are the activities in the purchasing function which require high consideration for legal aspects?
- 3 What are the approaches for price determination.
- 4 What are the various purchase forms and records usually employed by a purchasing department?
- 5 How are vendors evaluated?

II Design Exercises (Purchase System and Procedure)

- 1 Design a suitable form to be used for preparing the comparative statements to enable the purchasing manager to take the decision about the best supplier.
- 2 Design an inspection report form to enable the purchasing department to release various installments of the payment and to enter the appropriate data in the supplier's file.

III Problems (Purchase System and Procedure)

- 1 An item is demanded at the rate of 20,800 units per year and the lead time is 2 weeks. The unit price is Rs.50 and the holding cost is Rs.10 per unit per year (i.e. 20 percent of the unit price). It costs Rs.20 for each lot of procurement. The standard deviation of the demand over the lead time is 10. Calculate the order quantity, reorder point and safety stock and prepare the purchase plan and the budget for the whole year. [Ans: 1year

= 52 weeks assumed. $Q=289$, safety stock=30(3 times std deviation),
Reorder point=830, number of orders=72(approx.)]

- 2 Consider a problem of comparing suppliers by weight point plan. A total of 100 points are allocated among those factors considered important by an organisation. The supplier with the largest number of weight points is the most desirable. The following weights are used to compare the suppliers: quality (40points), price (35points), and service (25 points). Based on the data given below, rank the four suppliers:

Supplier	Shipment received	Shipments accepted	Unit price	Fraction of commitments fulfilled
A	500	480	10.00	0.94
B	600	560	9.60	0.90
C	80	78	1.20	1.00
D	200	192	8.90	0.98

[Ans: Fraction of commitment fulfilled i.e service rating factor

$$VPR_A = f_1 \cdot R_Q + f_2 \cdot R_P + f_3 \cdot R_S = 40 (480/500) + 35(1/1) + 25 (0.95) = 96.90(\text{III})$$

$$VPR_B = 94.83(\text{IV}), VPR_C = 99.00(\text{I}), VPR_D = 97.90(\text{II})]$$

NOTE: Price rating factor (R_P) = $P_L (100/P) = 100$ or 1

Where P_L = Lowest price quoted

P = price agreed by supplier

It is assumed that for each supplier $P_L = P$

Inventory Management

- 1 An organization is spending Rs.20 crores annually in procuring a total of 50,000 different items. Using simple empirical decision rule to group items into A,B and C category, determine the cut off values of annual usage that will decide whether the item should be A, B or C class item.
- 2 Write true or false against the following statements:
 - i) Perishable items should have higher value of inventory carrying charge than imperishable.
 - ii) EOQ is smaller if backlogging is permitted under deterministic demand.
 - iii) $\pm 10\%$ variation around EOQ is not very serious.
 - iv) Finite replenishment rates enable more economical operation of an inventory system.
 - v) Buffer stocks have no relationship with the amount of demand/lead time uncertainties.

- 3 In an inventory system the cost of placing an order is Rs.100/ order. The annual demand is 5000 units and the inventory carrying charge is 20% of the value per year. The item costs Rs.75 each. Find EOQ and total system cost if shortages are not to be allowed. [Ans: $Q^0=258$, TC= Rs 3873]
- 4 If shortages are permitted and allowed to remain back logged at a cost of Rs.60 per unit short/year, determine the **EOQ** , maximum stock level, maximum backlog level and the total system cost under optimal condition for the data pertaining to problem number 3 above. [Ans: $Q^0=289$, Max stock=231, Max backlog=58, TC=Rs 3464]
- 5 In an inventory system using classical **EOQ** model of Wilson, determine the range of variation of EOQ if 1% increase in cost over the minimum total cost is permissible. EOQ has been determined to be 400units.[Ans: 86.83% - 115.47%,(348 to 462)]
- 6 An item is demanded at the rate of 2000 units per year at a uniform rate. Ordering cost is Rs.350 per order. Inventory carrying cost is 24% of the unit price per year. The supplier has offered a unit price of Rs.100/ item but he is willing to reduce it to Rs.95/ item if a purchase order of 1000 units or more is placed. Should you accept this offer? [Ans: TC(EOQ)=Rs 2,05,797 > Rs 2,02,100 therefore offer accepted]
- 7 “Inventory management for slow moving expensive items should focus more on lead time reduction than any thing else”. Critically examine the statement.
- 8 Who should be responsible for inventory control? Discuss this statement from a departmental as well as top management points of view.
- 9 Consider the following situation:

An inventory system has four items to be procured from different sources. Procurement action is based on each item to be considered individually and independently. The following data have been obtained for demand and unit prices for each item:

Item, i	Demand D_i (units/year)	Unit price V_i (Rs./unit)
1	7500	200
2	4000	90
3	500	500
4	100	80

The inventory control manager argues vehemently that there is no way to estimate ordering and carrying costs but he is prepared to accept that ordering cost to fraction of carrying charge is constant for each item. Currently he is

following an ordering policy of using a 4-month supply of each item. He is under pressure to cut down inventory by 25% and is therefore about to adopt a policy of 3-month supply. Use exchange curve to show that he has better options available to him. What should he do? [Ans: Adopt a policy of 3-month supply]

12.22 FURTHER READINGS

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UNIT 13 STANDARDISATION, CODIFICATION AND VARIETY REDUCTION

Objectives

After completion of this unit, you should be able to:

- familiarise with the need and role of classification, codification and standardisation in the context of materials management from the viewpoint of planning, control, purchase, inventory, stores, and so on
- appreciate the importance of standardisation in variety reduction
- design and implement codification system for situation other than materials
- design and implement standardisation for procedures and forms etc. in information system design
- introduce computerisation of data system for materials using codification and standardisation.

Structure

- 13.1 Introduction
- 13.2 Classification of Materials
- 13.3 Codification
- 13.4 Standardisation and Variety Reduction
- 13.5 Summary
- 13.6 Key Words
- 13.7 Self-assessment Exercises
- 13.8 Further Readings

13.1 INTRODUCTION

Almost all organisations use and store a large number of items. Some of these have relatively longer life, for example, buildings, plants, equipments, machines and furniture etc. while others, in a rather large number, running into lakhs, spend shorter time with the organisation, for example, materials, components, tools and stationery, etc. We shall concentrate mainly on materials and parts.

Several departments of the organisation require the information about the materials and their requirements are usually different from each other. For example, it is easy to visualise how the information requirements may have quite a wide spectrum by departments such as receipt, storage, inspection, design, engineering inventory, accounts and marketing etc. about a given material. Some departments are interested in the size, volume and shape, some

in engineering properties, some in financial aspects while some in the commercial value of the material. It is quite likely and perhaps sometimes purposeful for an item to get identified by different names by different departments of the organisation. A dustbin may be known as refuse container, rubbish-box, etc. An electric company in UK had as many as 118 names, for a simple screw with a diameter of 3/8 in. and length of 6 in., depending on type of usage and the department using the screw. These may, however, result in confusion and tend to duplicate ordering or overstocking. The problem could really explode beyond dimension when the number of items is very large (as usually it is) and there are several external organisations, suppliers, wholesalers, retailers and customers etc. who prefer to call an item by different names: some by brand name, some by manufacturer reference number, some by engineering name, and some by serial number.

Quite often, a good number of products or parts may differ very marginally or insignificantly from each other in dimensional or some similar characteristics. The functional requirements will be equally well served if all such parts are made to the same common specifications. This is called standardisation. **The process of standardisation logically leads to reduction in the number of part, variety that an organisation handles.**

For the purpose of convenient understanding of the topic, we shall discuss classification, codification, standardisation, and variety reduction in that order.

13.2 CLASSIFICATION OF MATERIALS

Classification is defined as the process of arranging things in groups or classes according to their resemblances and affinities and gives expression to the unity of attributes that may subsists among a diversity of individuals.

When there are numerous items handled by an organisation, their planning and coordination becomes extremely difficult, if not impossible, if each one of them is handled separately. Classification of materials involves grouping of items according to some criteria. We are quite familiar with classifying our domestic articles into clothes, kitchenware, electric appliances, electronic gadgets, furniture, professional articles, entertainment articles, groceries, consumables and non-consumables etc. It is easy to see that an item may belong to more than one class depending on the criteria used. For example, a radio set is an electronic gadget as well as a non-consumable and entertainment article.

What is the purpose of classification? Following are the major objectives of classification:

- i) To devise procedures of planning and control for materials in a class.
- ii) To devise purchase procedures, inspection methods, and storing and issuing procedures, common to all materials in a class.

- iii) To devise accounting and evaluation procedures common to all materials in a class.

Obviously; the concentration of effort according to class system would be more efficient and effective as compared to diluted effort corresponding to each individual item.

Following are the major classification systems.

On the Basis of Nature of Materials

- a) **Raw Materials:** Raw materials include all those materials which are purchased from the original producer or other manufacturers and are used directly in producing the firm's product. For example, cotton and yarn are raw materials for cotton textile mills for they help in producing the final product- cloth. Cotton is purchased from the original producer, i.e., cotton grower, whereas yarn is procured from other manufacturers, i.e., spinners. The product in one trade may become the raw material for the other trade.
- b) **Machinery and Equipment:** All the machinery, both power and hand-driven, such as, presses, lathe machines, typewriters, electric motors, fans, and other machines used in the production and other departments, is classified as such. Tools also come under this category, and they are issued on loan basis to the various departments for a definite period, generally till their life-time.
- c) **Consumable Items:** Those materials used in the manufacturing process which cannot be used for the second time for the same purpose since their utility for the purpose in question has ceased and the shape changed are referred to as consumable items. Coal, coke, mineral oil, lubricants, cotton waste, paints, varnishes, oxygen, stationery items like pencil, paper, carbon papers and ink, etc., are a few examples of the consumable items.
- d) **Chemicals:** Substances obtained after undergoing certain processes in chemistry according to a formula devised for the purpose may be known as chemicals. They should be stored, preserved and issued very cautiously after a careful scrutiny and proper analysis since their use involves risk even to life. Items like carbide, acids and salts etc., can be classified under the head.
- e) **Inflammable Items:** Items highly susceptible to fire, such as petrol, kerosene, films, dopes and paints, fall under the category. Due to their hazardous nature, they are generally stored as far away as possible from the main building with complete fire-fighting arrangements standing by.
- f) **Fuel Stock:** These are also consumable items. But there is a slight difference between the two in respect of their uses. When an item is directly used for production and is a fuel for the furnace and, oven etc., it is classed as fuel stock. It is a necessary item for completing, rather starting, the manufacturing process and of course one of the important items in a manufacturing unit, but it can never constitute the finished product.

However, sometimes it may rightly be taken as a raw material. Coal is a fuel stock but is also a raw material for an iron and steel industry.

- g) **Furniture:** Movable contents of a house or a room like chairs, tables, almirahs, benches, and stools, etc., are furniture items. Their repairs, renewals and replacements also require proper maintenance of records since they are issued temporarily on loan basis.
- h) **Scrap Materials:** On the expiry of life of a particular item, the residue is called the scrap. Such material as is left over as waste in the process of production is also known as scrap. The scrap is sold out in the market so as to fetch some value out of it. Kabadis are the best purchasers of scrap in this country.
- i) **Packaging Materials:** These include all kinds of wrapping materials, such as paper, wood carvings, sawdust and straw, etc., containers like boxes, crates, drums and bottles, protective coatings, such as, wax, grease, as also plastic cans and bags, etc.
- j) **General Items:** This category include all those items which do not fall under any of the above categories of items. In a large undertaking, general stores section is separated from other stores under an independent incharge since they cover a large number of items, which, although not directly linked with the production processes, are required for day-to-day smooth and efficient running of the enterprise. Cleaning materials like soap, brasso, brooms, uniforms for the staff, stationery and all other items of general use are handled in the general stores department.

On the Basis of Usability of Materials

- a) **Serviceable, Unserviceable and Obsolete Items:** Serviceable items are those items which go temporarily out of order. After repairing and replacement they may become serviceable again and their usable life may thus be extended for some more time. Unserviceable items are those items which have outlived their life. No amount of repairs, renewals or replacements can bring them back to their usable life. They are thus fit only for disposal as scrap. Obsolete items are those items which have gone out of date because of new inventions in design and use, etc., and which cannot profitably be used again.
- b) **Finished and Semi-finished Items:** Finished items are those goods which have been manufactured in complete form by the production department and are ready for sale. On the other hand, semi-finished items are those which have not yet been manufactured completely and need some further processing before they can be put to sale in the market. They are thus taken back by the production department for turning them into a final product.
- c) **Dead Stock Items:** This term is generally used in government departments. Furniture, equipments, machinery and other items which have some definite life and which cannot be written off before the expiry date of their life are classed as dead stock items. They are issued temporarily on loan basis to their users.

- d) **Unused Items:** These are not stock items in the real sense of the term. These cannot be used in the production unit, because, being defective, damaged beyond use, or because of some other reason they have been rendered unusable. Sometimes unused stocks are mistaken for scrap and unserviceable materials. But this is not the real position. Scraps are generally left out items from the production unit. They cannot be used, as either they are less in quantity or less in measurement, weight, etc. But unserviceable items are movable items which have been rendered unserviceable by constant use and are now beyond repair.

13.3 CODIFICATION

From the above, it is clear that there must be some means of identifying the items accurately, uniquely, and adequately. These identification attributes are achievable by appropriate classification and codification. We are familiar with the PIN Codes used by Post and Telegraph Department to uniquely and concisely identify various regions of the country. **Codification is a process of representing each item by a group of numbers and alphabets indicating the group, the subgroup, the type and the dimensions of the item.** Many organisations in the private and public sectors, railways and DGS & D, have their own system of codification. The number of digits in a code may typically be somewhere between eight and thirteen. The role of these digits and some fundamental principle of codification can be understood from the following example:

digits 1-2 major group (raw materials, spare parts, subcontracted items, hardware items, packing material, tools, oil, stationery, etc.),

3-4 subgroup (ferrous, non-ferrous, etc.),

5-7 dimensional characteristics (length, width, head diameter, etc.),

8 minor variations,

9 location of storage,

10-11 user departments of the organisation,

12 product or product lines requiring the item,

13 any other information of inventory accounting and purchasing etc.

This is merely an illustration of codification, process. The codification process can be based on other aspects also. (i) The codes could be obtained by the nature of items in grouping all items. of the same metal content, say ferrous, non-ferrous etc. (ii) The system could be built sometimes on the basis of the end-use of items, say maintenance, spinning, foundry, welding, packing and machine shop, etc. (iii) The codification could be thought of on the basis of source of purchasing where items obtained from one source are grouped together. (iv) The codification could also be built on the basis of alphabetical listing.

Objectives of Codification

In order to identify the items correctly and logically for processing the transactions, and to facilitate easy location in stores, a codification system should be evolved with the following objectives:

- a) **Accurate and Logical Identification:** A separate code is allotted to each of the items available in the storehouse indicating the size, quality, price, usability, special characteristics and specification, etc. This distinguishes one item from the other, even if nomenclature is the same, helps in accurate identification and eliminates any possibility of confusion. For example, a lead pencil of black colour, HB quality, for writing purpose and within a price range of Rs. 3.00-3.50 may have its code as 07.39.1236 where
07 indicates the group (viz stationery item)
3 indicates pencil
9 indicates lead pencil,
1 indicates lead colour (viz. black)
2 indicates quality (viz. HB)
3 indicates use (viz. writing)
6 indicates price range (viz. Rs. 3.00-3.50).
- b) **Prevention of Duplication:** All items are separately codified and are arranged in a logical order. Similar materials are grouped together (such as stationery items) and given a code (e.g., 07). Once a code is allotted to a particular group, it is a decision on an organisational level and in no case it is changed. Since each item has a different code number and various items are kept in different bins at different places, there can be no duplication in placing the orders, and no piling up of the materials will take place in the storehouse.
- c) **Standardisation and Reduction in Varieties:** For codification, grouping of identical items is done and it enables the stores to examine the entire range of items. It facilitates the elimination of those varieties in place of which other varieties of the like quality can be used; this reduces the number of varieties to the minimum. If proper standardisation is achieved and the number of items is kept at the minimum, it will considerably reduce investment in various items as well as the cost of inventory carrying.
- d) **Efficient Purchasing:** The filling up of purchase requisition, and preparation of purchase orders are simplified by the use of codes which easily indicate the materials required. Buying instructions to the suppliers become easy and quick if there is proper understanding of codification by the supplier. The entire operation of the purchase department can be organised according to grouping of items. In centralised purchasing such a

system serves well in dealing with the purchase orders and in taking advantage of bulk purchasing.

- e) **Efficient Recording and Accounting:** Codes lead to effective stock control, efficient recording and result-yielding accounting. Chances of mistakes are minimised. Pricing and valuation also become more accurate and reliable.
- f) **Easy Locating, Indexing and Inspection:** The materials in the store have to be kept in an order which may facilitate their placement and location. For making it less time and energy consuming, items may be arranged according to the codes allotted to them. This would also facilitate a quick and efficient inspection.
- g) **Easy Computerisation:** Small size computers such as Personal Computers (PC) are finding their wide applications in materials management. The computers work better with codes than with long description of materials.

Essential Features of Codification System

There could be many possible arrangements of coding symbols (numbers, alphabets, etc.) which can be used to design a code. However, a great deal of thought must go into the coding scheme if it is to satisfy a variety of users. The following considerations must be kept in mind when designing codes.

- a) **Brevity:** The codification system should avoid long and unwieldy description. This implies that the codes should consist minimum possible number of digits. The size of the code would normally be dictated by the number and range of items and the number and types of applications of the data pertaining to the item. For example, for the pencil code 07.39.1236, the last digit representing the price range may be deleted if such information is not needed.
- b) **Logical:** The coding system should be logically fit for the needs of the users and the methods of data processing employed. For the example of pencil code, the last digit representing price range should have an increasing price range with the value of the digit increasing, that is, a value of digit as 8 may indicate a higher price range of say Rs. 4.00-4.50
- c) **Flexibility:** The code design should be flexible to accommodate changes without disturbing existing codes. We are familiar with the library coding system in which codes do never get disturbed by addition of new books and all books to come in future are easily accommodated by the existing code structure.
- d) **Uniqueness:** Each code must be a unique representation for the item it identifies. For example, an inventory item number or employee identification code must identify one and only one inventory item or employee.

- e) **Easy Understandability:** The code structure must be easily understood by various users. It should be as simple, practical and meaningful as possible.
- f) **Proper Choice of the Coding Symbols:** While a code may have numbers, alphabets or a mixture of both, certain precautions should be taken in selection of the symbols. Characters with similar appearances should be eliminated. For example, the letters O, Z, I, S and V may be confused with the numbers O(zero), 2, 1, 5 and U, respectively. Where possible, letters that sound the same should be avoided (for example, B, C, D, G, P and T or M and N).
- g) **Layout of Codes:** The layout of code should be equal in length. For example a code 001-199 should be preferred over I-199. Codes longer than four alphabetic or five numeric characters should be divided into smaller segments for human judgements.
- h) **Capacity of a System:** When calculating the capacity of a given code for covering all situations while still maintaining code uniqueness, the following formula applies: $C=S^p$, where C is total available code combinations possible, S is the number of unique characters in the set, and p is the number of code positions. For example a 3-digit code with numbers 0 to 9 will have $10^3=1,000$ unique code combinations. The size of code structure, therefore, should be decided before hand by anticipating the requirements of the unique combinations.

CODIFICATION Systems

There are several systems possible for codification of materials depending on the choice of coding symbols-alphabets, numbers, or a combination of alphabets and numbers (alphanumeric). Two popular and fundamental systems-Brisch and Kodak- are described here.

- A) **Brisch System:** The Brisch system is based on numbers from 0 to 9 and consists of blocks (typically three) separated by decimal points. The blocks are assigned specific classification of the materials. The first (left most) block represents the major classification (such as raw materials, packing materials, finished materials, etc.), the second block represents the next level classification (such as nature, use, quality, characteristics, etc.) while the third block represents the lowest level classification (such as quality of the material, its components; its facial appearance, price, availability, source of supply, marketability and frequency of use, etc.). The following example for stationery items explains the Brisch system. The major item stationery is classified into four groups based on the nature of each item and each group in turn is divided into further subgroups.

Item Particulars	CODES			
	Main	Subcode I	Subcode II	Full Code
Stationery	63			
Pencil	..	01	..	63.01
Pen	..	02	..	63.02
Paper	..	03	..	63.03
Ink	..	04	..	63.04
Pencil				
Black	..	..	41	63.01.41
Blue	..	..	42	63.01.42
Red	..	..	43	63.01.43
Blue Red	..	..	44	63.01.44
Pen				
Ball-point	..	..	51	63.02.51
Fountain	..	..	52	63.02.52
Holder	..	..	53	63.02.53
Inkstand	..	..	54	63.02.54
Paper				
White	..	..	35	63.03.35
Brown	..	..	36	63.03.36
Typing	..	..	38	63.03.38
Duplicating	..	..	39	63.03.39
Ink				
Blue	..	..	12	63.04.12
Black	..	..	14	63.04.14
Red	..	..	15	63.04.15
Duplicating	..	..	17	63.04.17

The system proceeds in the following steps:

- The materials to be coded are grouped together so as to form a major group. The grouping should be accurate and unambiguous, and should not overlap. It is based on the classification system described in the previous section,
- After the classification or preliminary grouping, the materials are further divided and sub-divided as explained earlier. The basis of these division and sub-division describes the materials in as great detail as possible and simultaneously making them relevant to the users.
- The codes are assigned in three blocks separated by decimal points. Total number of digit could be any as per convenience but a general figure is 7 (seven).

B) Kodak System: The Kodak system has been developed by Eastman Kodak Co. of New York, USA and is supposed to be a very comprehensive system. It consists of 10 digits of numerical code. The basis of the major or first level grouping is source of supply. All materials are divided into 100 basic classifications based on purchase and procurement considerations. For instance, a bolt is listed as hardware item if this is listed in hardware catalogues and available with hardware suppliers. If this bolt, however, is available only as part of the machine, it will be available under maintenance. Each class is divided into 10 sub-classes. For example, if class 20 represents cutting tool, then 200 represents drills, reamers and counter bars, etc. The steps of classification can be understood by the following example:

Step I. Major (First Level) Classification (based on purchase and procurement consideration)

First Two Digits Class Code	Materials
00-20	Raw Materials
21-35	Machine and Mechanical Equipments
36-40	Mechanical Products and Loose Tools
41-49	Electrical Products and Electrical Equipments
50-52	Laboratory Equipments
53-68	Chemicals, Equipments, and Miscellaneous Chemical Products
69-78	Office Equipments and Other Misc. items.
79-83	Furniture and Fixtures
84-87	Fuel Stock
88-93	Semi-finished and Finished Product
94-99	Miscellaneous

Step II: Sub (Detailed) Classification of materials in class code say 53-68 (Chemicals, Equipments and Miscellaneous Chemical products).

Second two Digits sub-class code	Materials
53	Tanks
54	Pumps
55	Mixers
56	Packaging Machines
57	Plastic Materials
58	Paints
59	Lubricants
60	Acids
61	Solvents
62	Phosphorus
63	Sulphur

Step III: Further Sub-classification indicating kinds in a particular sub-class of materials say 60 (acids).

Third Digit (0-9) Sub-sub-class code	Materials
600	Carbonic Acid
601	Sulphuric Acid
602	Sulphurous Acid
603	Unassigned
604	Unassigned
605	Unassigned
606	Unassigned
607	Unassigned

608	Unassigned
609	Unassigned

Step IV: The kind of the materials may further be divided into different types. For example 601 indicating sulphuric acid may further be classified indicating the type of the sulphuric acid. For example, one may classify the types of sulphuric acid as,

- 86 Type A
- 87 B
- 88 C
- 89 D
- 90 E
- 91 F

This level has two digits while the previous level had only one digit. This is possible. There is no strict pattern to be followed about the number of digits and the level of the classification. The two digit code in Step IV indicates suitably the percentage of acid content.

The process of classification and sub-classification may continue to accommodate subsequent levels of variations. The code may have some digits left unutilised for future expansion. For example a code 601-87-XX XXX indicates chemical product (53-68 group) and in that acid (60), and in that sulphuric acid (1) and in that Type B (87). The digits XX -XXX are left for future expansion.

Colour Coding Systems: Sometime colour codes are used to identify the items. Common instances are, red, blue and green in an electric cable, red and green in electric switches, and so on. Some organisation use the codes locally such as to identify the steam, water and other pipes while there exist some national or international colour coding system. The limited number of colours available narrows the scope. This is however quite an effective system providing easy identification.

Drawback of Codification

- (1) Sometimes the codes become so complicated that it is difficult to understand.
- (2) Coding of some characteristics like tolerance level of finish and degree of automation is quite problematic.
- (3) Wrong identification may be possible if codes are not clear, colour codification may create confusion among materials (and meaningless for colour blind workers)
- (4) It may be confusing to the vendors to handle two or more organizations simultaneously to supply them the same article having *different codes* by them as per their own convenience and requirement.

- (5) Some alphabets used in the codes such as I,U,S,B and O may be wrongly confused with the similar notations like 1(one), V(vee), 5(five), 8(eight) and 0(zero) respectively and that may lead to erroneous identification of articles.

13.4 STANDARDISATION AND. VARIETY REDUCTION

Standardisation is the process of formulating and applying rules for an orderly approach to a specific activity for the benefit and with the cooperation of all concerned in particular for the promotion of optimum overall economy taking due account of functional conditions and safety requirements.

A standard is defined as a model or general agreement of a rule established by authority, consensus, or custom, created and used by various levels of interest. For instance, an individual may be the starting point of using standard and then his department will use the same standard to suit its needs. The firm may similarly prepare, by consulting different departments, a standard for guiding the activities. Related industries in the industry group may also prepare industrial standards. At the national level, by consulting manufacturers, scientists users and government departments, national standards are evolved. Such national standards lead to the evolution of international standards. The standards could cover a variety of industries, such as engineering, textile, chemical, pharmaceutical, agricultural as also education. The topics covered under standards can include purchase contracts, forms, sampling, testing and safety measures, etc.

In the context of materials, we are already aware of use of standards for specifying the items, especially for purchase purposes. Market grades, commercial standards and performance specifications are the popular examples of wide range applications of standardisation.

Standardisation enables the materials manager to achieve overall economy and ensures inter-changeability of parts. With standardisation more than one manufacturer can supply and this will imply better availability, better price and better delivery. Standardisation also implies routinising purchase efforts, less stock and hence less obsolete items. It also Means less inspection efforts; as a matter of fact, many organisations do not check routine items bearing ISI marks in a very detailed manner. but resort to inspection of only a small fraction of items. It is also possible to enter into rate/running contract with standard items. This facilitates the production planning and economic lot-sizing at the supplier's end.

The process of standardisation logically leads to simplification or variety reduction. This implies reducing unnecessary varieties and standardising to the most economical sizes, grades, shapes, , colours, types of parts and so on. In large organisations handling lakhs of item, it is quite possible that there are

several items having very little variation in quality, dimension or functional effectiveness. The items can be analysed for their frequency of usage over the past few years. Such frequency or movement analysis would bring out items which are seldom used or not used at all. On the basis of this analysis, the organisation could get the standards to replace these items. The process of standardisation and variety reduction can be summarised as follows:

- 1) Prepare the list of all items used to make the final product. The list can be made out of the design blue-print in case the product design is just over but production has not started, or from the actual record of consumption in case the product is in production.
- 2) Classify the items according to their performance (or function) and dimensional characteristics.
- 3) Group the items with similar functional characteristics and then subgroup according to major dimensional values. For example, all bushes around 5 cm dia will be in one group while all around 3 cm dia will be in other group and so on.
- 4) For a group of items with similar functional characteristics, study the dimensional features. In case of large number of items, several item with the same or similar functional requirements, are likely to show the dimensions clustered in a very closed vicinity. Analyse the effect on performance of items if all items are made to the most representative (mean or mode of the frequency distribution) value of the dimension. If the performance characteristics are within satisfactory zone, these items are produced of the same dimension. It may be noted that this is a very important step in variety reduction.
- 5) Check from the national or international standards if there is already a dimension existing equal to the most representative dimension found after analysis in the previous step. If such a dimension is found, the items can be deemed as standardised. If an exact dimension is not found, select the closest dimension and study again the performance of all items in the group around this dimension. If performance is acceptable, the item has been standardised according to national or international standards. If the performance is not satisfactory, organisation will adapt a local standard, the dimension being of the representative value.

In addition to the dimensional and performance characteristics of materials, standardisation concepts are equally meaningful for the forms, procedures and reports etc. in relation to purchase, stores, and even planning activities.

Benefits of Standardisation

The important benefits are summarised as below:

- (i) Standardisations helps reduce inventory items increasing efficiency

- (ii) It helps in evolving better means of communication. Common standards for weights and measures and traffic signals etc. ensure better communication in our world of innumerable different cultures and languages.
- (iii) It ensures interchangeability and thereby convenience to use various products. Plugs and sockets, batteries and bulbs of different brands are interchangeable.
- (iv) It aims to ensure safety of human life. A helmet is an example of personal protective equipment(PPE) used by industrial workers, firefighters and 2-wheeler riders.
- (v) Standards also aim to protect health. Standards on infant milk food and infant formulae ensure that there are adequate nutrients for optimal growth of the child and in standards for food products, limits are set for elements injurious to health.
- (vi) Standards have been developed to safeguard the environment from pollution by prescribing limits for toxic emissions from industries and automobiles.
- (vii) Hallmarking on gold and silver ornaments effectively arrests the fraud and forgery on the making and sales of precious jewellery.
- (viii) The specification of items can be more clearly spelt out, making quality control firm
- (ix) In a developing economy like ours, where the need is to promote exports, insistence on standards helps in creating confidence in the international market.
- (x) With standardization also comes overall economy, reduction in cost, minimization of human effort and conservation of essential materials.

By using national standards, it is easier to locate sources of supplies and in the case of machine parts, the replacements can be obtained easily. It could also be used in advertising for the products as well as spare parts.

Effective steps have been taken in a number of organisations in India for cost reduction in the number of stores items. The aim of standardisation should be to have uniform standards for similar items, and the standards evolved should take cognizance of the indigenous availability of the materials to the maximum extent possible. With these broad national objectives in view, Bureau of Indian Standards(BSI) has developed and promoted more than 20,000 standards covering raw materials, components, and finished products by the end of the year 2021.

Disadvantages of Standardisation: The following are the disadvantages-

- (i) Change of public taste or liking, fashion and trend may seriously effect a company producing only standardized product range

- (ii) It reduces the variety of products to be offered to the consumers and the workers feel bored and fed-up doing the same routine again and again if too much standardization is enforced
- (iii) The process of product development is hampered due to monotony and non-flexibility of the product range.

13.5 SUMMARY

Organisations deal with a large number of materials with varying degree of characteristics in terms of size, shape, price, physical and chemical properties, sources of supply, modes of handling, user departments (destinations) and accounting procedures, etc. In addition, there are several departments of the organisation which require only the information about the materials, e.g. design, engineering, production scheduling etc. In order to meet these complex requirements the items need to be classified properly.

Often, an item would require a very long description to get uniquely and adequately identified. Using number and alphabets with appropriate meanings, the description can be reduced to six to thirteen digits. This helps in easy retrieval of information and data processing. Several aspects of the codification have been discussed for the readers and users to follow a standard system or to enable to design own system.

Several items with similar functional and dimensional characteristics can be grouped to a single dimension and other technical characteristics with negligible loss of functional requirements through the standardisation. This helps in reduction of variety of items in the stores. This concept of standardisation is well suited for standardisation of things beyond materials such as processes, inspection procedures, forms, charts and reports etc. The standardisation also makes the users aware of the performance expected from the product.

13.16 KEY WORDS

Brisch System: A codification system using numbers in blocks separated by decimal points. Usually it consists of 7 digits.

Classification: Grouping of items with similar attributes.

Codification: Condensing the long information with the help of few digits comprising alphabets and numbers. The location of digits and their values suggest the meaning of the information.

Kodak System: A codification system consisting of 10 digits of numeric characters.

Standardisation: Process of grouping of items to conform to widely acceptable representative features and characteristics.

Variety Reduction: Process of reducing a large variety of items with close characteristics to fewer items (through standardisation).

13.17 SELF-ASSESSMENT EXERCISES

I. Review Questions

1. What are reasons for classifications, codifications, and standardisation of materials?
2. What are the common classification systems?
3. What are the advantages of codification?
4. What are the possible disadvantages of the codification?
5. What are the essential requirements that a coding system should satisfy?
6. What are the differences between Brisch and Kodak systems?
7. How does standardisation help in variety reduction?
8. What are the steps in variety reduction programme?
9. What are the roles of Indian Standard Institution (ISI)?
10. How standardisation would help consumerism?

II. Design Exercises

1. You are the incharge of the purchase department of an organisation. The department is responsible for receiving the requisition form from various departments, processing them, selecting the supplier, determining the price, time, and quantity of purchase. The department as usual would prepare various reports for the management. The organisation would also be interested in vendor development and evaluation.
2. You are to design a suitable coding system for identification of files of correspondence externally as well as inside the organisation.
3. Consider the following data pertaining to a shirt company.

Sleeve length	Price
Neck size	Market region
Colour	Sales person
Style	
Material	

Design. a suitable coding system with appropriate selection of the coding symbols.

13.18 FURTHER READINGS

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UNIT 14 WASTE MANAGEMENT

Objectives

Upon completion of this unit, you should be able to:

- conceptualise Waste, realise the scope and need for a systems' approach to waste management, identify the multi-disciplinary character of waste management and establish the relationship between wastivity, productivity and resource management
- realise the need for adopting a preventive policy of waste generations, devise and apply suitable means for waste reduction, realise the importance of devising good systems for waste collection, recycling and disposal, appreciate the necessity or introducing concept of waste in the traditional input-output model and devise a method of cost accounting for wastes.

Structure

- 14.1 Introduction
- 14.2 Complementarity of Waste Management and Resource Management
- 14.3 Taxonomy of Wastes
- 14.4 Definition of Wastivity: Gross and Net Wastivity
- 14.5 The Functional Classification of Waste Management
- 14.6 Outline of I-O-W (Input-Output-Waste) Model
- 14.7 Treatment of Wastage in Cost Accounts
- 14.8 Concluding Remarks
- 14.9 Summary
- 14.10 Key Words
- 14.11 Self-assessment Exercises
- 14.12 Further Readings

14.1 INTRODUCTION

The diverse and seemingly boundless developments taking place in industry bring with them a whole new series of complexities associated with waste. From a systems' viewpoint, waste is any unnecessary input to or any undesirable output from any system encompassing all types of resources. **Waste Management (WM) is a multi-disciplinary activity involving engineering principles, economic, urban and regional planning, management techniques and social sciences, to minimise the overall wastivity of the system under consideration.** A systematic approach to waste management encompassing the waste of all kinds of resources at all stages should be adopted. However, as the material constitutes a major fraction of the total product cost, material wasted are of critical importance.

14.2 COMPLEMENTARITY OF WASTE MANAGEMENT AND RESOURCE MANAGEMENT

A system basically takes some input, processes it and gives the desired output, as shown in Figure 1, i.e., some input is essential, in whatever form for the functioning of a system. An ideal system is conceptualised to transform the total input into useful or desirable output. In view of the known physical laws of nature the existence of an ideal system is not possible, i.e., 100 per cent utilisation of resources is not practically possible for any system. To paraphrase, some waste is inevitable in the functioning of any system.

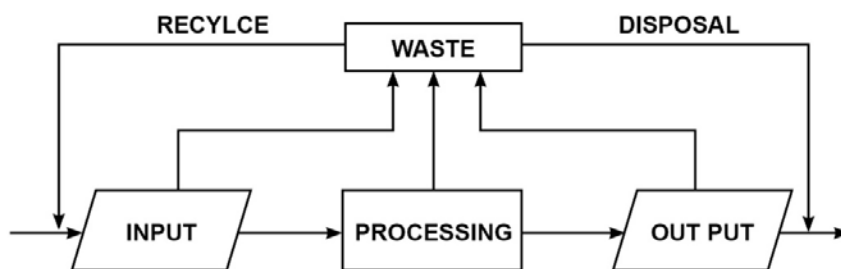


Fig I. Input- Processing- Output system

The main objective of WM is to minimise the waste thus aiming at the ideal system, while the resource management aims to maximise the utilisation of the resources. The goal of waste and resource management is same, i.e., optimal utilisation of the available resources for higher efficiency and growth of the system; but the approaches are different. The relationship of waste and resource management is shown in Fig II.

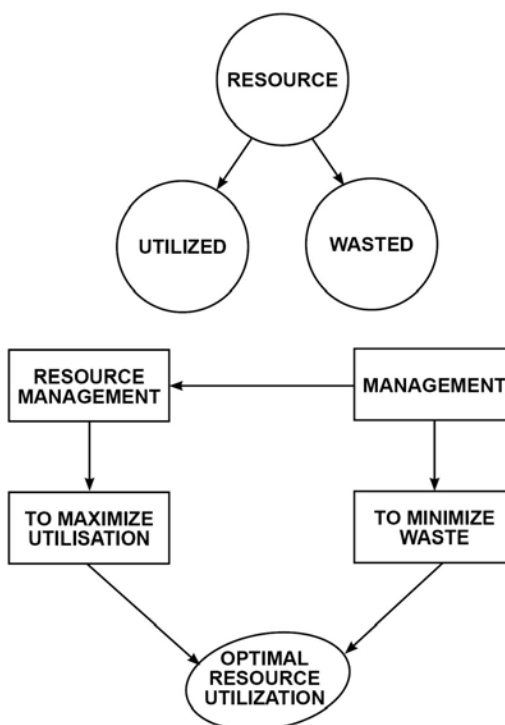


Fig II. Complementary Relationship of Waste Mngt. And Resource Mngt.

It can be said that waste and resource management are complementary to each other. If one is primal formulation of a problem, the other is a dual. Both approaches have their advantages and limitations. Depending upon the situations, the constraints and primary and secondary objectives, resource management techniques prove to be promising in some cases, while in others WM offers an added advantage.

14.3 TAXONOMY OF WASTE (The science or technique of classification of waste)

Lack of coordinated work in the field of WM has given rise to multiplicity of terms and definitions of various types of wastes. The need for standardisation of the nomenclature has been felt for systematic research and effective implementation of WM programmes. Wastes can be classified in a variety of ways depending upon the purpose for which classification is done. There could be four basic classifications as follows.

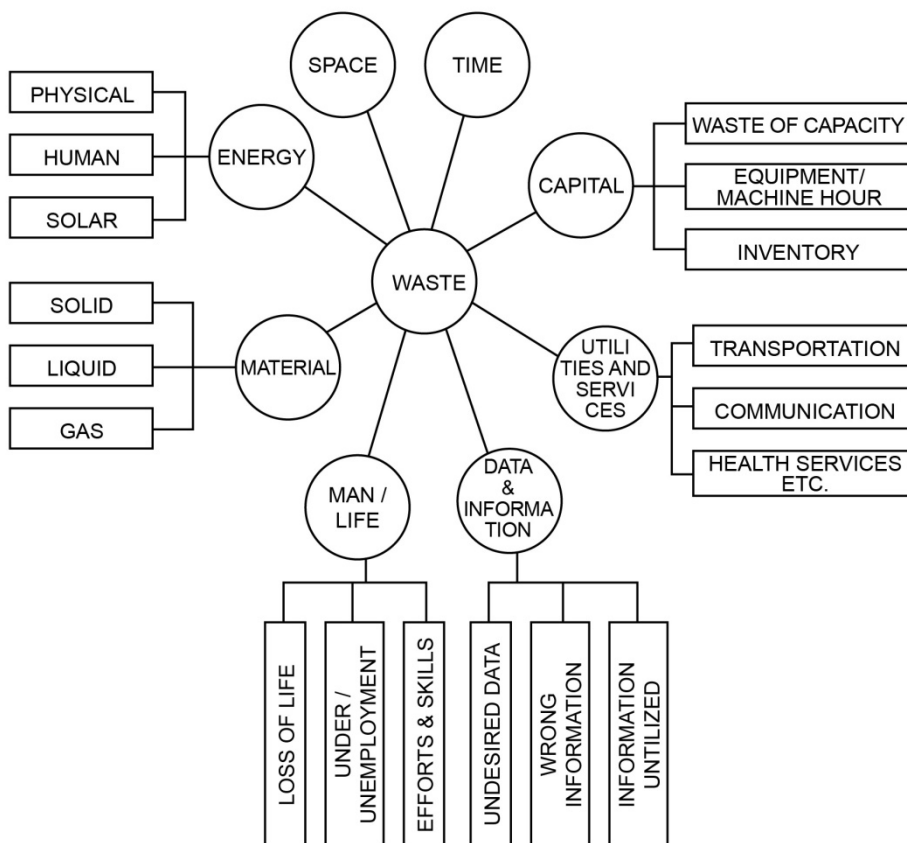


Figure III: Resource Based Classification of wastes.

- a) **On the basis of the resource wasted:** Various types of resources are wasted at various stages in the system. Taking the resource as a basis, the classification of waste is shown in Figure III.
- b) **On the basis of source of origin:** The source of origin may serve as an efficient and practical way of classifying waste, e.g.,
 - i) Agriculture

- ii) Industrial
 - iii) Municipal
 - iv) Residential or domestic
 - v) Commercial
 - vi) Construction and demolition etc.
- c) **On the basis of property:** This classification is meant for material wastes only; depending upon the property that effects the environment, waste may be of two types:
- i) Hazardous
 - ii) Non-hazardous
- d) **On the basis of recoverability:** As per the characteristic of resource the waste may be:
- i) **Recoverable:** The waste that can be converted into some useful resource, e.g. material waste, energy waste reused in other processes, etc.
 - ii) **Non-recoverable:** This includes the resources that are lost with time and cannot be regained afterwards, e.g. manpower, energy, capacity and services. etc.

14.4 DEFINITION OF WASTIVITY: GROSS AND NET WASTIVITY

Most of the productivity measure at present compare the total output to individual inputs, viz., material, energy, manpower and capital etc, while they usually fail to directly compare the fraction of a particular input that goes into output. Further, it is difficult to measure the output of various individual inputs invested in various finished products, whereas it is comparatively easier to assess the waste of various inputs. Hence a new concept of “Wastivity” has been propounded, that can serve as an adequate measure of performance of any system, and is rather easy to measure

“Wastivity of any system is defined as the ratio of the waste to the input”.

$$\text{Wastivity} = \frac{\text{Waste}(W)}{\text{Input}(I)}$$

Depending upon the level of waste under consideration the wastivity may be categorised as gross wastivity, and net wastivity.

“The gross wastivity is defined as the ratio of total waste generated by a particular system to the total input to that system”.

$$\text{Gross wastivity} = \frac{\text{Total waste generated}}{\text{Total input}}$$

However, a fraction of total waste generated is intermediate to the system and gets recycled. Thus the net waste to be disposed off or reused in other systems is less than the gross waste generated.

Net waste = Total waste – generated Waste recycled within the system

“The ratio of the net waste to be disposed of to the total input to the system is termed as net wastivity”. The net wastivity will be dependent on the extent of recycling.

$$\text{Net wastivity} = \frac{\text{Net waste generated}}{\text{Total input}}$$

Wastivity as a Performance Measure

An ideal or perfect system will be one that consumes just the right amount of resources, leaving no idle, unutilised (nonrecoverable) or lost resource, or any undesirable output. The presently known laws of nature obviate the existence of any such idea system, indicating that the occurrence of waste is inevitable. The concept of “Wastivity” which is yet in the rudimentary stages may prove to be a good measure of performance, both at macro and micro levels, and will be helpful in the sound planning and monitoring of various systems at different levels of hierarchy.

Wastivity and Productivity

Waste can indirectly serve as a good measure of productivity. “Productivity of any system has been defined as the ratio of the desired output to input”. Most of the productivity measures at present compare the total output to individual inputs, viz. labour, material, energy and capital etc. , while they usually fail to directly compare the fraction of a particular input that goes into output.

Hence a new concept of ‘Wastivity’ had been propounded, which can serve as an adequate measure of performance of any system and is rather easy to measure.

Let I_r be the wastivity index of r th resource and W_r be the relative weightage (depends upon a number of tangible and intangible factors) of r th resource, then

$$\text{Composite Wastivity Index} = \sum_{r=1}^n W_r I_r$$

For n types of resources Where, $\sum_{r=1}^n W_r = 1$

It will be very convenient to measure the waste as well as input for each type of resource for a specified period.

We have,

$$I = O + W$$

Dividing both sides by I , we have

$$\frac{I}{I} = \frac{O}{I} + \frac{W}{I}$$

or $1 = \text{Productivity} + \text{Wastivity}$ or $\text{Productivity} = 1 - \text{Wastivity}$

The Wastivity for each type of input thus indirectly assesses the productivity for each type of input. Both productivity and wastivity are complementary to each other, which bears in it the inherent cause and effect phenomenon. If the cause, i.e. wastivity is checked, the effect, i.e. productivity, will automatically be improved.

14.5 THE FUNCTIONAL CLASSIFICATION OF WASTEMANAGEMENT

The problems associated with the management of wastes in today's society are complex and diverse in nature. For an effective and orderly management of wastes the fundamental aspects and relationships must be identified and clearly understood. The efficient WM comprises of the quick identification of the waste generated/caused, economic reduction, efficient collection and handling, optimal reuse and recycling, and effective disposal of waste leaving no environmental problems. WM can thus be functionally classified into five basic elements, viz., generation, reduction, collection, recycling and disposal. However, WM should be viewed in totality considering the inter-relationship of basic functional elements/system as shown in Figure IV. One of the objectives of WM is to optimise these basic functional systems to provide the most efficient and economic solution, commensurate with the constraints imposed. By considering each element separately it is possible to:

- i) identify the fundamental aspects and relationships involved in each element,
- ii) develop, wherever possible, quantifiable relationships for the purpose of making engineering comparisons, analysis and evaluation.

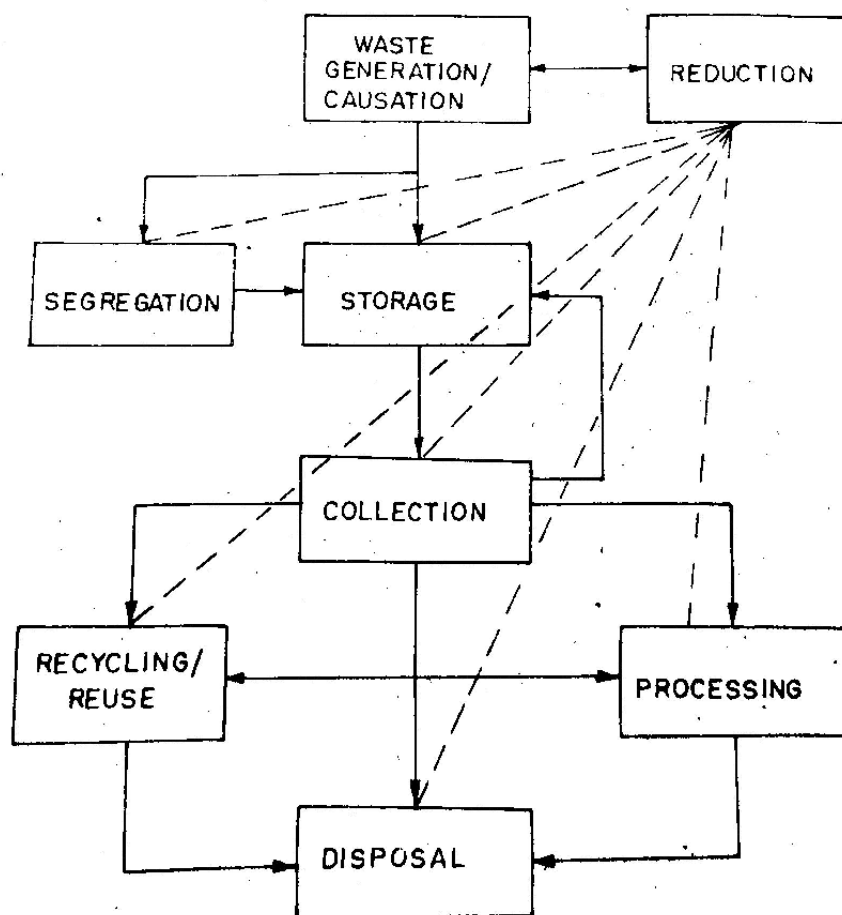


Figure IV: Functional Elements of Waste Management

Generation of Waste

There may be numerous causes responsible for the generation of waste in different systems. However, some general causes of waste generation at different stages had been perceived. The check list of causes of waste generation is shown in Table 1 out of which some causes may be critical. If it is possible to account for the amount of waste generated against respective causes, then the most critical cause will be one that contributes to the highest aggregate cost of waste.

Table 1

Checklist of Causes of Generation

- 1) Ineffective policies
- 2) Lack of Planning
- 3) Political pressures
- 4) Defective organisational structure
- 5) More emphasis on sub-system objectives rather than organisational goals
- 6) Poor management
- 7) Faulty systems and procedures

- 8) Personal interests
- 9) Carelessness and neglect
- 10) Lack of individual responsibility
- 11) Non-acquaintance with latest technological development
- 12) Resistance to adopt automation and computerisation
- 13) Wrongly laid-down design standards
- 14) Lack of standardisation and codification
- 15) Wrong choice of raw material
- 16) Ignorance of inventory control
- 17) Inappropriate storage facilities
- 18) Poor handling of materials
- 19) Poor layout of facilities
- 20) Information delay
- 21) Improper work methods
- 22) Less emphasis on PPC function
- 23) Inadequate supervision and control
- 24) Improper recruitment and lack of training
- 25) Lack of motivation and incentives
- 26) Unhygienic work environment
- 27) Insufficient skill and use of unsafe practices
- 28) Poor labour relations
- 29) Frequent power failures
- 30) Poor maintenance
- 31) Less emphasis on quality control
- 32) Poor distribution network
- 33) Less emphasis on collection and segregation of waste
- 34) Technological obsolescence
- 35) Miscellaneous causes.

Accurate information on waste generation rates and composition provides a basis for the design and operation of various waste control programmes, recycling and processing plants, waste disposal projects, and the choice of most effective disposal alternative. The problems in obtaining the information on this aspect are complex and involve following factors:

- Various establishments may differ widely in their waste generating practices.

- Most firms are reluctant to reveal production and related statistics for fear of the data being used to the competitive advantage of others.
- Generally, the firms are reluctant to provide information on quantity and composition of waste for fear of it indicating non-compliance with pollution-control regulations.
- The quantum of waste generated reflects the inefficiency of the organisation.
- Some industrial activities are subject to seasonal variations.
- The extent of salvaging, recycling or other reclamation of wastes differ greatly among manufacturers.
- Many firms themselves have little understanding of, and few records on this aspect.

A Systematic Approach to Waste Reduction

A systematic approach to minimise the total system waste minimising the waste at individual stages in conjunction with other stages has become proposed in Figure V.

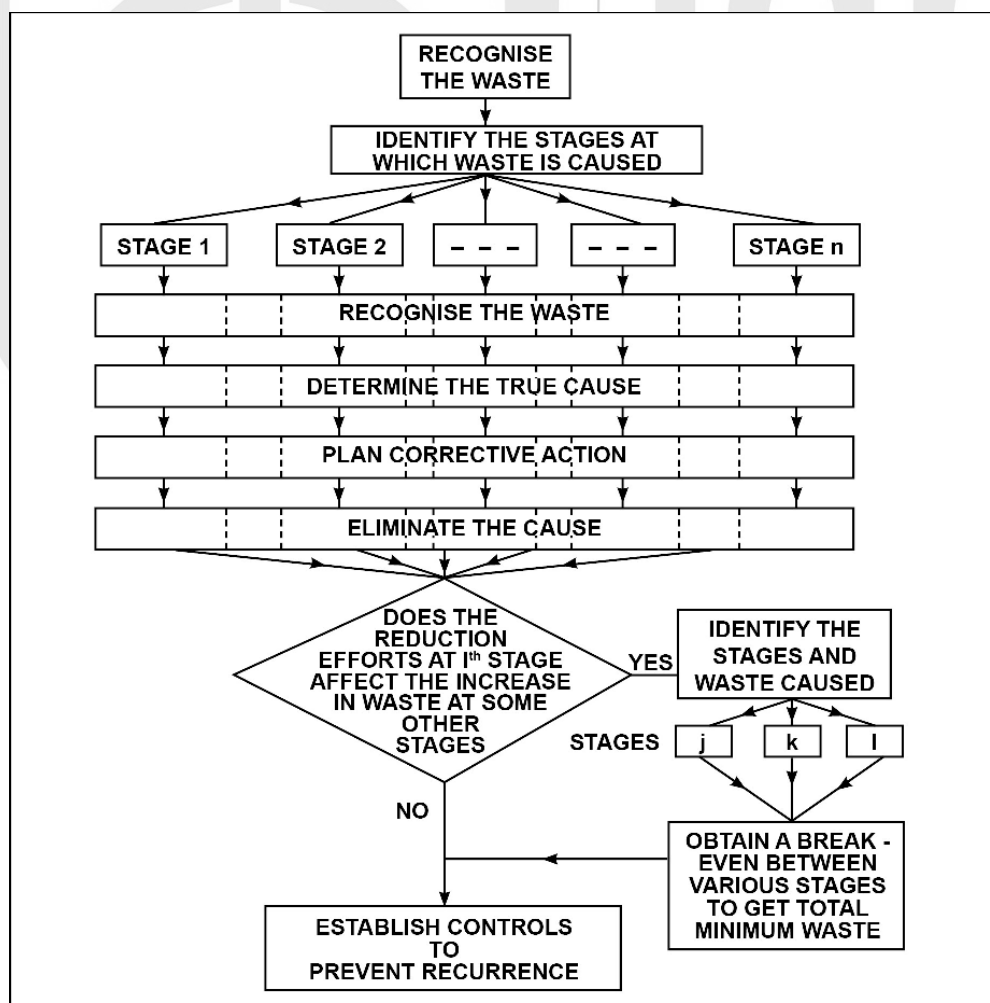


Figure V: Stage Wise Waste Redaction: A Systematic Approach.

It provides a scientific and systematic method for waste reduction at individual stages and finally for the whole system. The procedure for approaching from whole to part, and, then, from part to whole is proposed. The basic steps of the approach are as follows:

- i) Recognise the waste for whole system.
- ii) Identify the stages at which waste is caused/generated.
- iii) Visualise the whole waste into fractions caused at various stages as identified in step(ii).
- iv) Apply the systematic waste reduction procedure at each stage separately, i.e.,
 - recognise the waste,
 - identify the cause,
 - plan corrective action,
 - eliminate the cause.
- v) Find the correlation of various stages to assess the effect on waste generation at one stage due to waste reduction at other stages.
 - If there is no such correlation, then establish controls separately at each stage to prevent recurrence of the cause of waste generation.
 - If such correlations exist and waste is caused, then find the stages affected.
- vi) Try to obtain a break-even of wastes at the related stages so as to minimise the total aggregate waste at all the stages.
- vii) Establish controls to prevent recurrence of the cause of waste generation.

The Waste Management systems for individual organisations, sectors as well as the whole economy should be designed to fulfil the goal of zero waste. Zero waste should not be misinterpreted as if no waste is generated. Such an interpretation will be neither feasible nor justified. As some waste is inevitable with the function of any system, a 100% efficient system is only hypothetical. Further, such a system will be closed and will have a zero growth rate which is not desirable. The main theme of the philosophy of zero waste is to (first of all try to minimise the waste generated as far as it be technologically and economically feasible; and whatsoever little waste is generated should be put to some effective use.

The goal of zero waste should be visualised from systems point of view, i.e. to have zero waste of all types of resources simultaneously. Otherwise, it may be futile to aim towards zero waste for one type of resource if it causes the waste of another type of resource.

Waste Collection Systems

Waste collection has got a significant effect on subsequent functional elements, public health, aesthetics, housekeeping and public attitudes concerning the

operation of the system. As collection and transportation constitute a major cost in waste treatment (up to 80 per cent), streamlining of collection techniques can greatly improve the efficiency, and effect a significant saving in the overall cost of WM. This will be beneficial in two ways, viz., reduced disposal efforts and advantages of resource recovery by effective recycling of waste.

The proposed strategies for waste collection are:

- i) Design of economic basis to facilitate separation at source.
- ii) To provide every organisation with a set of four standard bins to separately collect the metallic, plastic, paper and other miscellaneous waste, the bins should be designed after careful investigation of the types and quantum of waste generated.
- iii) Design of appropriate collection system governed by public or private agencies to regularly collect the segregated waste at time intervals depending upon the generation rate.
- iv) Incentives to encourage segregation of the waste at source.
- v) Timely collection of 'scrapped organisations' appliances along with segregated waste, and its flow through salvage industry for ultimate reuse.
- vi) Development of appropriate collection systems for the collection of miscellaneous organic and inorganic waste.

Recycling of Wastes

In the absence of conservation or recycling, certain of the World's finite resources will diminish to a level incapable of maintaining an acceptable environment and adequate life support. Fortunately, in India, there is a growing awareness to recycle/reuse the waste. The National Committee on Science and Technology (NCST) has identified number of recycling projects.

The terms recycling, reuse, reclamation and recovery have different interpretations, though these terms are generally used as synonyms. In this study the term recycling is adopted to mean all these terms.

Recycling generally refers to the use of undesirable outputs or wastes as input to the same process or system, e.g., recycling of foundry scrap. Reuse may be termed as the use of waste generated from one process/system as input to some other process system as a raw material, or for the generation of power or by-products.

The conversion of damaged, rejected and undesirable outputs into the desirable outputs by repair or processing is termed as reclamation. The term recovery is utilised to denote the gain of resources from the wastes.

The recent developments of recycling of waste in our country have been noted with concern:

- 1) New jersey for the players of cricket and football is being prepared from the used water bottles (STAR-India).
- 2) Plastic sieves made from the damaged and rejected polyethylene bags for separating coarse grains from the fine ones are under circulation for domestic use:
- 3) A great achievement is made by manufacturing composite coloured wall tiles with the help of nano-technology by using old tattered carpet wastes and worn and torn door mats. These tiles are heat and sound resistant.
- 4) Environmental friendly writing papers are being prepared from the recycled plastic bags, chappals and containers.
- 5) Flowers and other *pujah* materials after performing the rituals from places of worship like temples etc. are recycled for the making of agarbattis, dhupbattis and artificial leather.
- 6) Great progress has been made to make buildings from flyash bricks and highways with plastic waste and rubber combined.

The list does not stop here. Many more such innovating ideas are taking concrete shape regularly in India to make the planet earth a lovely and eco-friendly place to live in.

Waste Disposal Systems

This element links the waste management system with environment and other systems, and has got a significant impact on the same. The adoption of poor disposal practices have resulted in severe environmental pollution in different parts of the world, particularly in the big industrial centres and have posed serious threat to human life. Some of the developed countries have taken the problem on war-footing and have started developing and adopting latest technology in this regard. In India the awareness has grown recently and the design of effective waste disposal systems has become a challenging problem area. From disposal viewpoint wastes may be categorised into:

- i) Salvable waste, and
- ii) Non-salvable waste.

The wastes that have got some salvage value are termed as salvable waste. The scrap, rejected goods, surplus / obsolete items and equipments etc. fall under this category. The well designed disposal system for salvable wastes may provide best return to the organisation, contribute to cost reduction and higher profit and aid to material conservation.

Wastes which do not have any salvage value, but need further processing and treatment for disposal are termed as non-salvable waste. The non-salvable wastes are primarily responsible environmental hazards. Proper management

of salvable wastes may amount to resource recovery and reduced environment and other social costs.

A) Guidelines For Disposal of Salvable Wastes: The salvable waste, e.g. scrap, surplus/obsolete stores and equipment, unserviceable appliances and machinery, abandoned vehicle etc. is generated in almost all sorts of manufacturing and service providing establishments. No particular attention has been paid in most of the organisations for the disposal of salvable wastes. The most common practice is to dispose the scrap surplus through auctioning. No systematic procedures have been developed in this regard. Another mode of disposal adopted is to salvage the scrap through specialised agencies. The traditional “*Kabaris*” or Junkmen are performing this work. Directorate General of Supplies and Disposals (DGS & D) is playing a vital role in public disposals. It disposes the stores worth several crores of Rupees, every year for various Government Departments. A special Surplus Disposal Committee was set up for analysing the large quantities of accumulated surplus. The Committee in consultation with Metal Scrap Trade Corporation and Minerals and Metals Trade Corp. Ltd (MMTC) has suggested some procedures for the manner of disposal and the market analysis of the huge ferrous and non-ferrous scrap in the country.

The procedures for the disposal of different types of salvable waste vary from situation to situation. Some broad guidelines have been suggested to aid the design of systems and procedures for disposal in individual cases:

- i) First of all the feasibility of recycling should be analysed to dispose the scrap.
- ii) Try to use the scrap for producing by-products.
- iii) Try to transfer the surplus from one department to another or to other plants in case of multi-plant organisation.
- iv) Analyse the feasibility to sell the scrap as raw material to other plants.
- v) To sell the scrap surplus to external export agencies dealing with it.
- vi) Selling of scrap through advertisement and auctioning. The frequency of auctioning should be decided after analysing the generation rates and by obtaining a break-even between the scrap/surplus carrying cost and auctioning cost.
- vii) Selling the surplus in open market, or to the employees itself, particularly in case of consumer goods. If the product is not meeting the quality requirement, then classify it as seconds and give a discount. This may act as an incentive to employees.
- viii) To consult the vendor and return the surplus to vendor.
- ix) To sell surplus/obsolete equipment through advertisement and invite the offers from other parties.

- x) In case of damaged equipments try to sell the parts after classifying into the categories of good, serviceable, repairable or reclaimable, and scrap.
- xi) To donate the rejected material to charitable organisations to gain socio-economic respect.

(B) Processing and Disposal Techniques for Non-salvable Waste:

Processing techniques are used in solid waste management system to improve the efficiency of operations, i.e. , to reduce storage requirements, facilitate disposal to recover resources, conversion products and energy, and to minimise harmful environmental effects. Disposal is the 'no alternative' option and the ultimate fate of all wastes that are of no further value. Various alternative processing disposal techniques have been briefly discussed as follows:

Mechanical Processing: The mechanical processing of the waste is done to reduce its volume and size for easy handling and disposal and to recover valuable materials by separation.

- i) **Compaction:** This technique reduces the volume of the waste by mechanical compaction.
- ii) **Baling:** This is also a mechanical volume reduction method which uses specialised compaction equipment to produce solid wastes in block or bales of various sizes. This offers the advantage of less landfill requirements, neat and clean operation of land filling, easy transportation and thus saving in cost of covering material etc.
- iii) **Shredding:** This refers to the mechanical size reduction of wastes by pulverising. The volume is reduced up to 50% and a homogeneous mass is obtained which is relatively odourless, unattractive to flies and vermins, and is relatively non-combustable leading to easier disposal. Milled refuse can be disposed of, at locations close to residential areas.
- iv) **Component Separation:** Component separation is a necessary operation in the recovery of resources from solid wastes both manual and mechanical method can be used. The separation may be done at the source or centralised separation may be adopted.

Thermal Processing: Thermal processing of wastes result in volume reduction, generation of energy and by-products. The overall heat contents of solid wastes including moisture and ash etc. is approximately 10.5 million BTU/Ton, which is most nearly comparable to that of low rank lignites.

- i) **Incineration:** High temperature oxidation of the organic and toxic compounds present in gaseous wastes is employed to destroy the offensive effluents and odours by converting them into harmless gases, i.e. Oxygen and waste vapour.

ii) Pyrolysis: The pyrolysis of solid wastes strictly refers to the destructive distillation or the thermal decomposition of the wastes in an inert atmosphere.

Bio-Processing: For agriculture based economy like India bio-processing is becoming an important research field to produce fertilisers, alternative fuels and feeds etc. Some bio-processing methods are composting, fermentation, and hydrolysis etc.

Composting: Composting of solid wastes may be defined as the bio-chemical stabilisation of those organic materials to a humans like substance through scientifically producing and controlling an optimum environment for the process.

There is vast potential for composting as a disposal process in India. It has been used from long time in rural area, but there is a need to make the people aware of its benefits and rigorous organised efforts should be made.

Ultimate Disposal: Ultimately something must be done to solid wastes that are of no use and are left after recycling and processing etc. The option available is the disposal in the earth's mantle (e.g. land filling).

Sanitary land filling: Sanitary landfills have been proclaimed as the low cost, safe way of disposing of municipal refuse. Rain water and surface run off water percolates through the landfills and the resulting leachate has a high concentration of organic wastes and harmful salts. Also, the evolution of methane gas from the refuse can create fire and explosion hazards.

C) Design of Effective Waste Disposal System: The design of effective waste disposal system is an important aspect of waste management. The system should be designed to promote the maximum possible recycling/reuse of wastes, and for minimum environmental hazards. The flow diagram of waste disposal system has been shown in Figure VI.

First of all the technical economic and social feasibilities of recycling/reuse should be analysed and attempts should be made to recycle the waste as it is without any processing. If the residue left after optimal recycling/reuse is disposed as it is, then the mode of disposal should be selected; otherwise various processing techniques should be evaluated by considering various social and economic factors. Both the source as well as centralised processing methods should be selected properly. Finally. Plans should be prepared for the ultimate disposal.

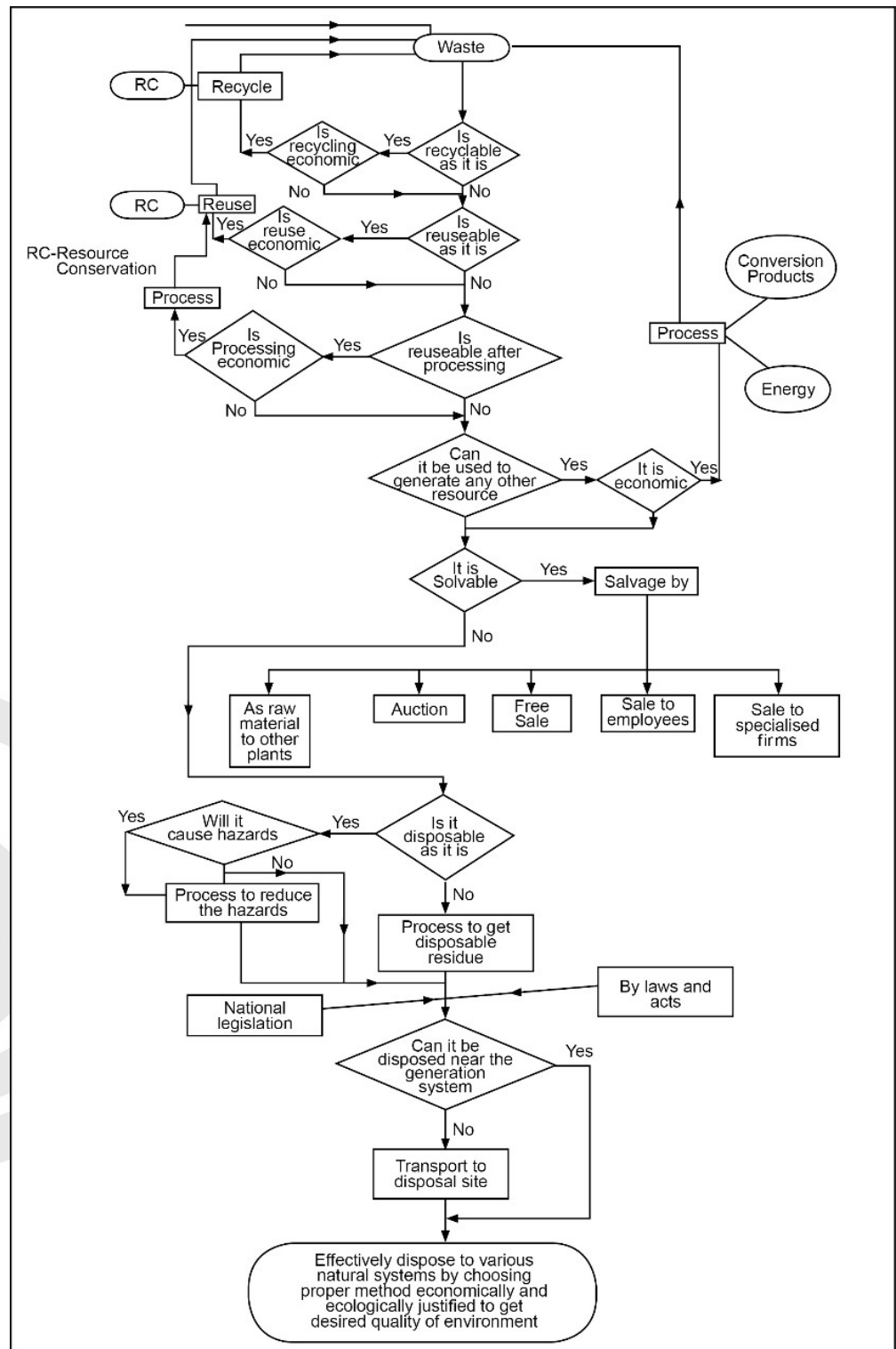


Fig vi. Flow Diagram of Waste Disposal System.

Various factors that should be considered in the design of waste disposal system are:

- i) The public attitudes
- ii) The regional and national policies
- iii) The economic considerations
- iv) Land availability

- v) Equipment requirements
- vi) Ground water protection
- vii) Environment control
- viii) Fire prevention
- ix) Litter control
- x) Operation plans
- xi) Employer facilities
- xii) Equipment maintenance
- xiii) Operational records

14.6 OUTLINE OF I-O-W (INPUT OUTPUT-WASTE) MODEL

It has been visualised that it is possible to take waste as an explicit parameter and the existing input-output model can be modified to incorporate WM constraints. To provide a closer representation of real life system it is proposed to remodel them in the framework of an I-O-W (Input-Output-Waste) model. The proposed model will be able to define the resource balance more realistically by incorporating the reduction, recycling, abatement, disposal and related functions of WM. The I-O-W physical system defined the resource constrained for every viable system as the balancing of inputs to the sum of outputs and wastes for each type of resource:

$$\text{Input} = \text{Output} + \text{Waste}$$

Basic Framework: The basic framework of I O-W model defines I-O-W flow matrix, I-O-W coefficient matrix and consistency equations. The I-O W flow matrix consists of a set of conventional intermediate demand or resource flow matrix extended to include WM sectors final demand matrix plus added waste flow matrix. An aggregated I-O-W matrix is shown in Table 2.

Table 2

I-Q-W Flow Matrix

Intermediate demand or Resource flow matrix	Final demand matrix	Total output
Input of resources	Total final demand	
	Waste flow matrix	Total waste
Total input = Resource inputs + Recycled Wastes		

The I-O-W coefficient matrix consists of technological coefficient matrix, final demand coefficient matrix and WM coefficient matrix partitioned for intermediate and primary inputs, and intermediate and final wastes as shown in Table 3.

Table 3

I.O.W. Coefficient Matrix

Consuming Sectors		
	Technological coefficient matrix (intermediate input coefficient)	Final demand coefficient matrix
	Primary input coefficient	Primary input to Final demand
	WM Coefficient Matrix Intermediate Waste Coefficient	Final Waste Coefficient

The model may be generalised for 'n' production sectors and 'm' WM sectors. The source of primary inputs are aggregated as trade, habitat and nature, whereas the final demand is clubbed into domestic consumption trade and change of stocks. The inter-sectoral waste flow is treated as intermediate waste, while final wastes include waste recycled in habitat by changing life styles, waste disposed of by trade and the wastes ultimately disposed of to nature.

14.7 TREATMENT OF WASTAGE IN COST ACCOUNTS

It is realistic to expect that all materials put into process will not end up as good saleable product. Some loss, scrap and wastage are inevitable in process industries. These losses must be computed in advance before the processing operation begins. Process loss can be divided into two categories; (i) Normal loss, (ii) Abnormal loss. Normal loss is the loss which is unavoidable, uncontrollable and expected in normal conditions. It may be inherent in the manufacturing process. If the loss is inevitable, i.e. unavoidable and within the limit, it is called normal process loss. Abnormal process loss is controllable and generally caused by abnormal or unexpected conditions, such as bad designing, poor materials, accident and negligence etc.

The treatment of normal and abnormal losses differ in inprocess accounts. Normal losses are absorbed by good production. Assume, for example, that 25,000 units of a mixtures were put into process and that during processing 5000 units were lost through evaporation. This is an unavoidable loss. If the total cost recorded was Rs. 25,000 the remaining 20,000 units would be assigned a unit cost of Rs. 1.25

$$\frac{\text{Cost of Production}}{\text{No. of Units Completed}} = \frac{\text{Rs. 25,000}}{\text{Rs. 20,000}} = 1.25$$

Abnormal losses are valued as good units. The unit cost which is used to value good units is also applied for the valuation of abnormal loss units. The cost of abnormal loss units computed in this manner is transferred to a separate abnormal loss account and credited to the relevant process account. Subsequently, this loss is transferred to the costing profit and loss account and the abnormal loss account is thus closed.

The following procedure will help in the preparation of process cost accounts that do not present any difficulty:

- 1) Normal loss should be computed on the basis of information given in the question.
- 2) The cost per unit of production, after taking into account normal loss units, should be determined assuming that abnormal loss does not exist. The cost per unit is calculated on the basis of the following information:
 - a) Normal production, i.e., inputs (units) minus normal loss units.
 - b) Normal cost of production, i.e., all costs incurred (appearing on the debit side of a process account) minus proceeds (if any) realised from the sale of normal loss units.

Normal cost of production divided by normal production will give the cost per unit of output.

- 3) The cost per unit determined as above is used to value abnormal loss units and that would be the cost of abnormal loss.
- 4) The abnormal loss account is debited and the relevant process credited with the amount and quantity of abnormal loss as calculated in (3) above.
- 5) The cost per unit as obtained in (3) will also be applied to determine the cost of good production units produced by the process.
- 6) The proceeds realised from the sale of normal loss representing scrap (if any) is transferred to the relevant process account.
- 7) The proceeds realised from the sale of abnormal loss representing scrap is transferred to a separate abnormal loss account and not to the relevant process account.
- 8) The abnormal loss account is closed by transferring the total cost of abnormal loss units to the costing profit and loss account if there is no scrap. In case abnormal loss represents scrap, only the net amount (total cost of abnormal loss units minus scrap) will be transferred to the costing profit and loss account.

14.8 CONCLUDING REMARKS

The problem of Waste Management should be visualised in a broader perspective and an organised systems' approach to Waste Management should be adopted. It is unfortunate that despite the cruciality of Waste Management in socio-economic resource structure in its ecological and environmental

compatibility, it has been ignored most of the time. There is a need to standardise the taxonomy of the wastes and to critically analyse the functional elements of waste management. Waste management is a dynamically emerging field with vast scope. Though awareness in this field is growing slowly, if proper attention is paid, it may rapidly gain momentum.

To accelerate the efforts to achieve universal sanitation coverage and to put the focus on cleanliness, Government of India has launched “Swachh Bharat Abhiyan” on the 2nd Oct 2014 on the birthday of Mahatma Gandhi to effectively handle the waste management

14.9 SUMMARY

In this unit we have proposed a new enlarged concept of waste and wastivity. The best way of waste management is not to generate waste at all, viz. a preventive policy of waste generation is advocated. We have established the close relationship between wastivity, productivity and resource management. A seven step systematic approach has been given for waste reduction. Guidelines for waste collection, recycling and disposal have been discussed. Some processing and disposal systems have also been overviewed. A brief outline of an input-output waste model has been given. It is difficult to accurately account for all wastages. Yet another procedure has been suggested that will help in the preparation of appropriate cost accounts.

14.10 KEY WORDS

Gross Wastivity: Ratio of total waste generated to total input.

Incineration: High temperature oxidation of the organic and toxic compounds present in gaseous wastes that is employed to destroy the offensive effluents and odours by conversion into harmless gases.

Productivity: Ratio of output to input.

Pyrolysis: Destructive distillation or the thermal decomposition of solid wastes in an inert atmosphere.

Waste: Any unnecessary input to or any undesirable output from any system encompassing all types of resources.

Waste Management: A multi-disciplinary activity involving engineering principles, economic, urban and regional planning, management techniques and social sciences.

Wastivity: Ratio of waste to input.

14.11 SELF-ASSESSMENT EXERCISES

- 1) Explain how the system concept can be used in explaining the terms waste and waste management.
- 2) 'Waste Management' is complementary to 'Resource Management'. Critically comment.
- 3) Differentiate between wastivity and productivity and explain whether reducing wastivity and increasing productivity imply one and the same thing.
- 4) What are the basic waste generation stages in a production system? Explain with the help of an example.
- 5) Explain how would you proceed in designing a waste disposal system for a manufacturing enterprise.
- 6) Write short notes on:
 - c) Systematic waste reduction procedure
 - d) Wastivity Indices
- 7) Write short notes on:
 - a) Identification of waste
 - b) Taxonomy of wastes
 - c) Systematic waste reduction procedure
- 8) Briefly explain what do you understand by the term IO-W (Input-Output-Waste) model.
- 9) Devise a method of cost accounting for wastes.

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